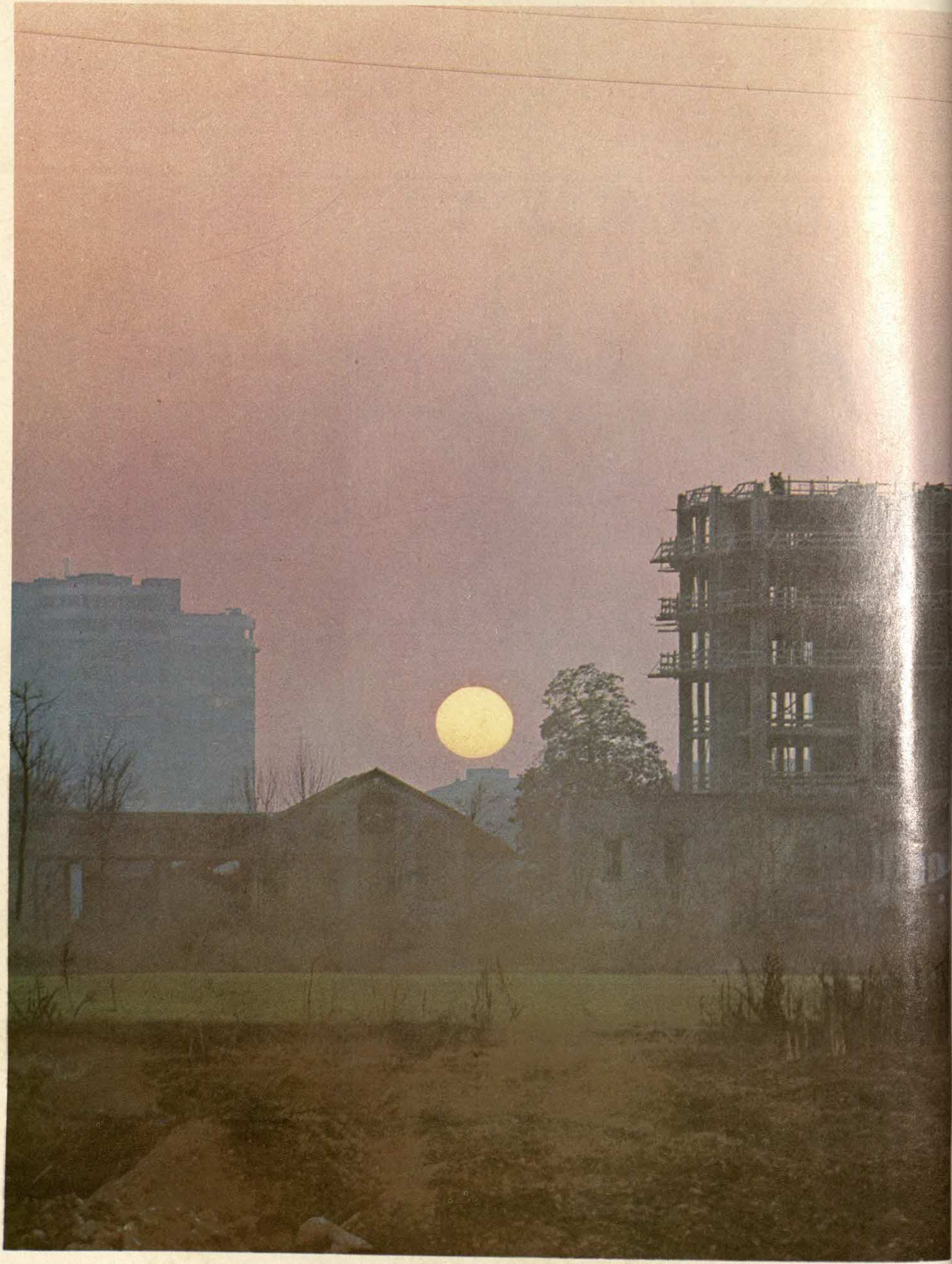
7

Illustrated World of Science Encyclopedia

Earth Science IV:
THE EARTH: ITS COMPOSITION AND STRUCTURE

THE WORLD OF SCIENCE



THE WORLD OF SCIENCE

VOLUME
7

EARTH SCIENCE IV

The Earth—Its Composition and Structure

with

The Illustrated Science Dictionary

CREATIVE WORLD PUBLICATIONS, INC.
CHICAGO

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Volume 7

EARTH SCIENCE IV

The Earth—Its Composition and Structure

INTRODUCTION

This volume brings together many different aspects of Earth science. Topics in geomorphology, mineralogy, economic geology, the geology of water, and meteorology are discussed in interesting articles about the Earth.

Throughout geologic time the crust of the Earth has been in continuous motion. Great mountain ranges have been built and then relentlessly destroyed by the processes of weathering and erosion.

During these changes in the crust of the Earth many different chemical elements were combined in precise relationships to create the minerals that constitute the rocks and that are so useful to man. Chief among the rock-forming minerals are the silicates, compounds that contain the elements silicon and oxygen. Combined with these two elements are hundreds of different proportions of many more elements, mainly aluminum, iron, magnesium, sulfur, sodium, and calcium. Together they form the feldspars, pyroxenes, amphiboles, micas, quartz and other minerals that together make up the rocks of the Earth.

As these rocks and their constituent minerals are weathered, the disintegration products form new minerals and new combinations of pre-existing minerals to provide material for rocks in even different forms. Thus the timeless processes of change go on year after year.

In addition to the elements comprising the rock-forming minerals, gold, silver, lead, zinc, copper and many of the elements used in modern technology also form mineral assemblages. Where these minerals are concentrated in sufficient quantity they are considered to be ore deposits. Modern geologists and geophysicists constantly are seeking new ways of finding these deposits, which in many instances are buried deeply within the surrounding rocks. Electrical, magnetic, and gravitational methods of geophysical exploration are used to hunt for these minerals. Intensive drilling programs then test the results of the geophysical surveys.

Other types of mineral assemblages may seem to be quite prosaic but nonetheless are of tremendous importance in modern life. Calcium carbonate, for example, as the mineral calcite in the form of limestone and marble, is used for building stone, for cement and concrete in construction, for decorative statuary, and for many other purposes. Other minerals that lack the glamour of gold, silver or copper, but that contribute a great deal to man's needs include coal, salt, sulfur, gypsum, and phosphate.

Several parts of Volume 7 consider the nature and motion of the sea of air in which we live. Because the atmosphere contains the element oxygen and carries water in the form of vapor, this subject is of fundamental importance. Moreover, because weather is brought about by the movement of air masses, man has developed a strong interest in observing these processes and in attempting to predict changes before they occur. The winds, humidity, barometric pressure, and cloud formations all contribute vital clues to forthcoming weather.

Volume 7 also discusses the interrelationships of climate and the hydrologic cycle. Of the rain that falls on Earth some evapórates, some runs off in the streams and rivers to the oceans, and some soaks into the Earth to become part of the ground water. This water percolates into the Earth and slowly fills the pore space within the rocks. Ground water usually is not static, but moves under the force of gravity. Where wells penetrate the rock formations below the level of the water and these formations are sufficiently porous to permit easy passage of the water, an excellent water supply usually can be developed.

In its passage through the Earth, water may dissolve mineral matter such as salt, calcite, and certain forms of iron. If this occurs to excess, the water may be unsuitable for drinking or for other uses, and some process of removing the minerals must be used. Inexpensive and safe methods have been devised to remove some of these minerals, and work continues to improve existing methods for the removal of salt from water.

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Head, Geophysics Section, and
Assistant State Geologist,
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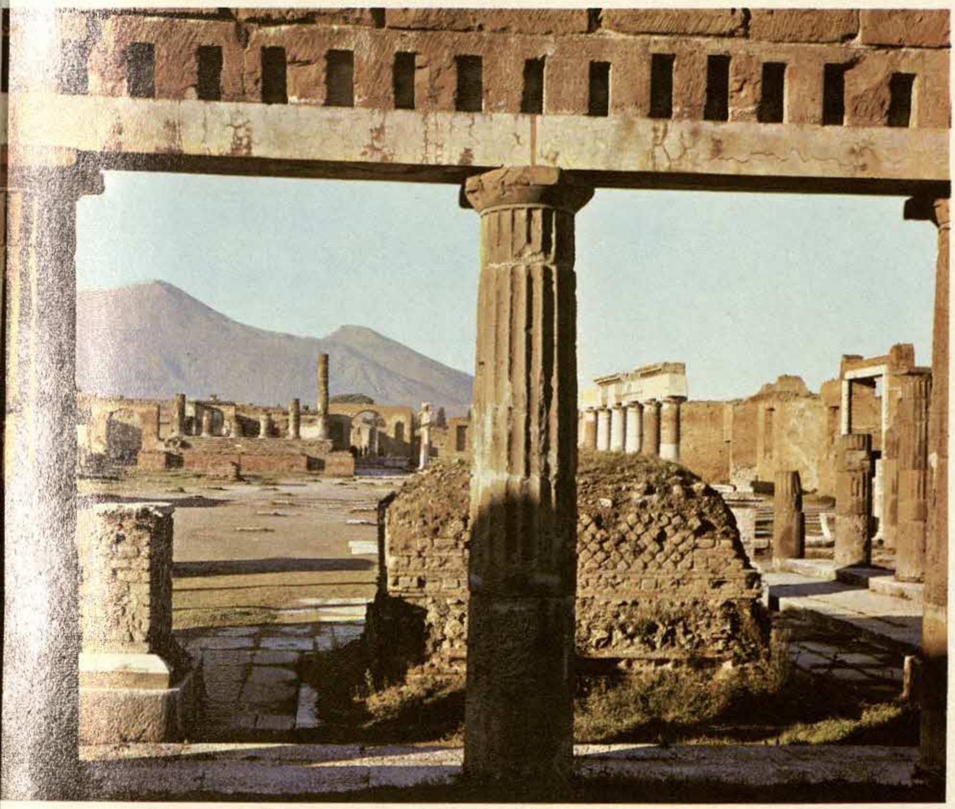
THE FORMS OF MOUNTAINS

the moving story of immovable giants

Who can gaze breathlessly at a great mountain without experiencing a sense of awe? Who can view the timeless wonder of the Grand Canyon without feeling small and insignificant? Can one scale a jagged peak without experiencing a sense of accomplishment—and a sense of fear? Who can examine a picture of Mount Fuji or Everest without longing to see the colossal monument in person?

Mountains move men. They stir human emotions and imaginations, but appear to be immovable and immutable themselves. However, the changelessness of mountains is only apparent, for nothing

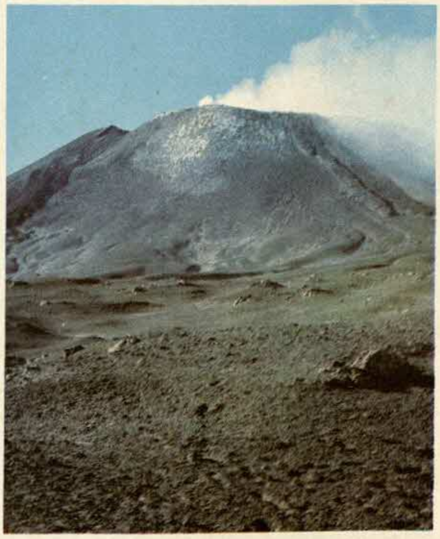
1a



THE FORMS OF VOLCANOES—The forms of volcanoes, more often than not, are determined by constructive forces rather than by erosion. Volcanoes, in fact, are mountains that have come into existence through the accumulation of materials ejected from inside the Earth; the form of a volcano tends to vary slightly according to the nature of the ejected material. The most common and characteristic form associated with volcanoes is the cone. When a volcano erupts, it usually spews dust, ash, and lava from a comparatively small opening, generally circular in shape; the material issuing from this opening is spread haphazardly in all directions. Thus, with the passage of time, the materials tend to be distributed more or less evenly all around the opening, thereby forming an almost perfectly symmetrical cone.

When lava issues from the mouth of a volcano, it flows downward toward the lower part of the mountain, cooling as it descends and gradually solidifying. Much of the lava remains attached to the slopes of the volcano, again contributing to the conical shape.

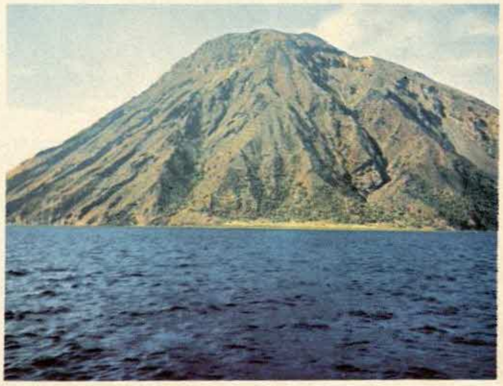
1b



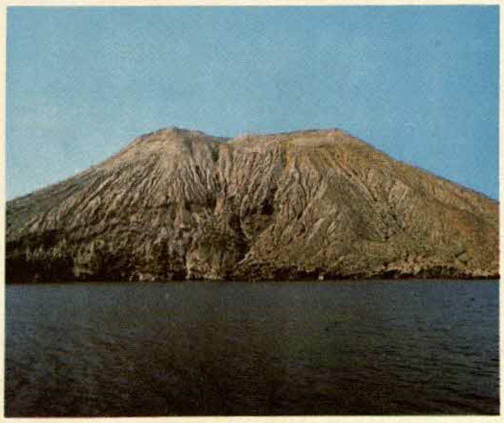
Volcanic dust and ash, particularly the larger particles, tend to fall near the mouth of the volcano; they would accumulate in this position if it were not for the fact that this material is very dry and slides easily. By way of analogy, one might try to construct a heap of dry sand by pouring additional sand directly on the top of the heap; he would, of course, produce a cone of sand. Vesuvius (Illustration 1a) is a good example of a volcanic cone; the entire upper part was formed by compacted dust (tuff) that accumulated in a very regular manner.

Mount Etna (Illustration 1b) also has a form that is more or less conical. Its slopes have been formed to a large extent by the solidification of lava from flows in both ancient and recent times. Mount Etna has very gentle slopes all around, because the lava ejected by this volcano has had a rather fluid character. Ordinarily volcanoes formed by flows of dense lavas have much steeper slopes than volcanoes that have ejected more fluid lavas.

1c



1d

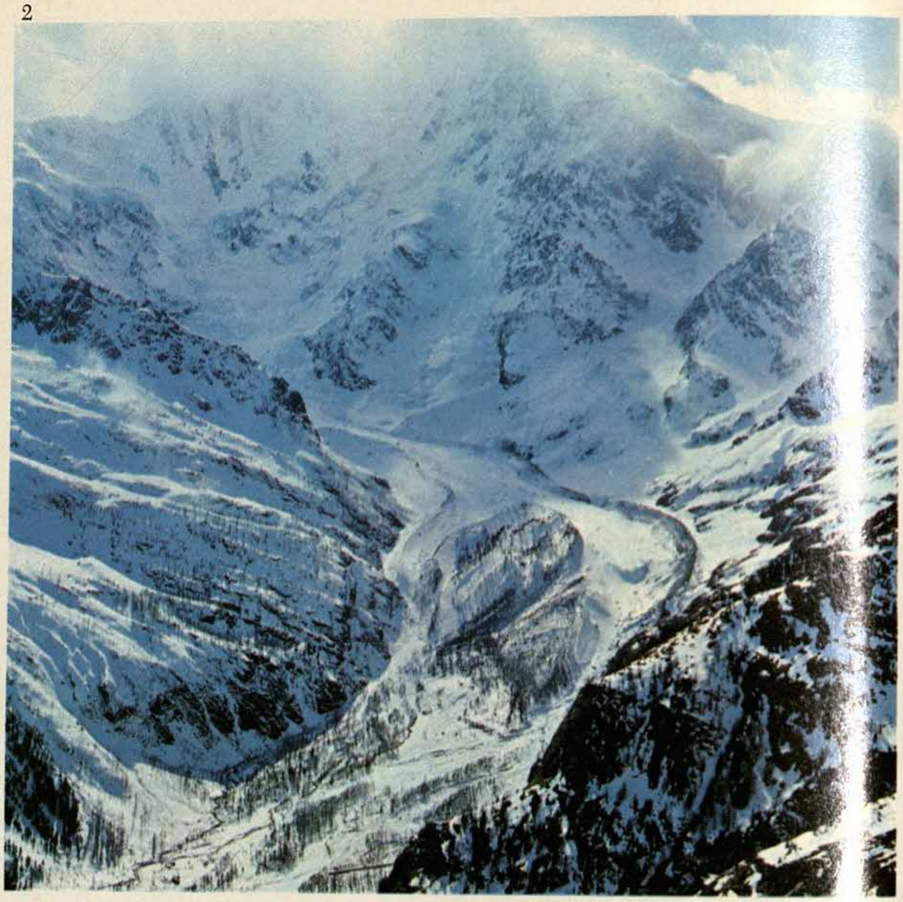


Stromboli (Illustration 1c) and Vulcano (Illustration 1d) are examples of volcanoes formed by flows of predominantly dense and viscous lavas.

MOUNTAINS AT THE HEADS OF GLACIAL VALLEYS—This photograph shows one of the faces of Mount Rosa in the Alps. A large number of glacial valleys lie below this large mountain; today these valleys have streams running through them, but in remote times they formed beds of colossal glaciers that filled them almost completely. The glaciers modeled or shaped the valleys, imparting to them their present appearance.

The glaciers began to form on the slopes of the mountain standing at the heads of the valleys. There, as first snows accumulated and as new snows fell, the snow became transformed into ice by compaction and recrystallization. As the ice accumulated, great tongues of this erosive agent began to move down the mountain into the valleys, carving out the landscape as they proceeded.

2



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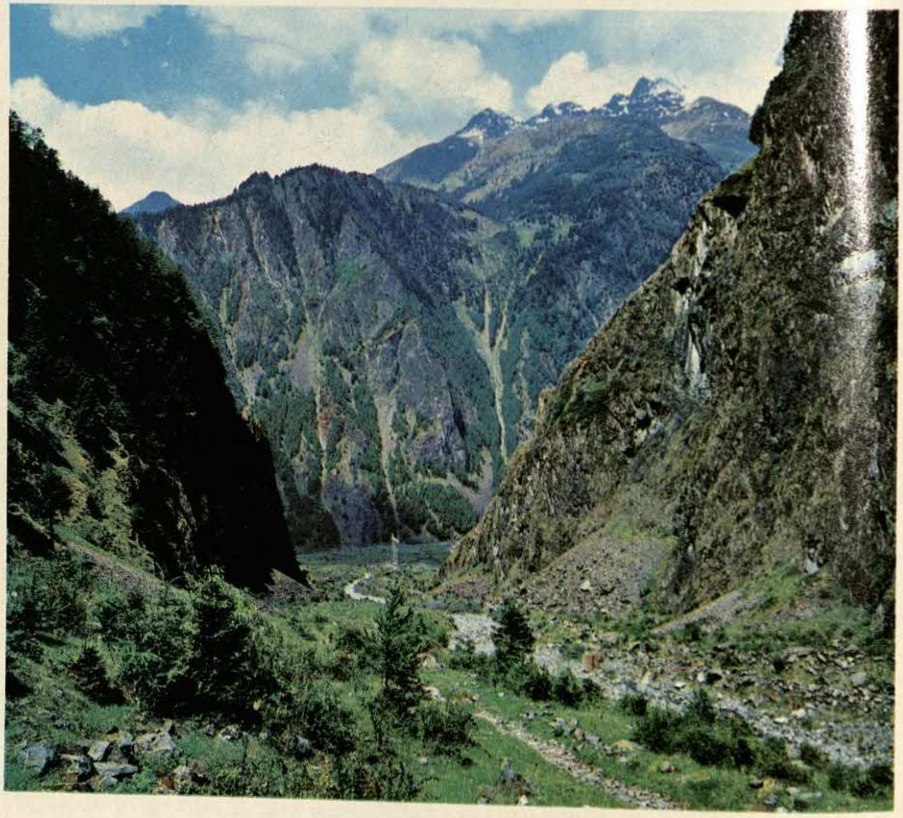


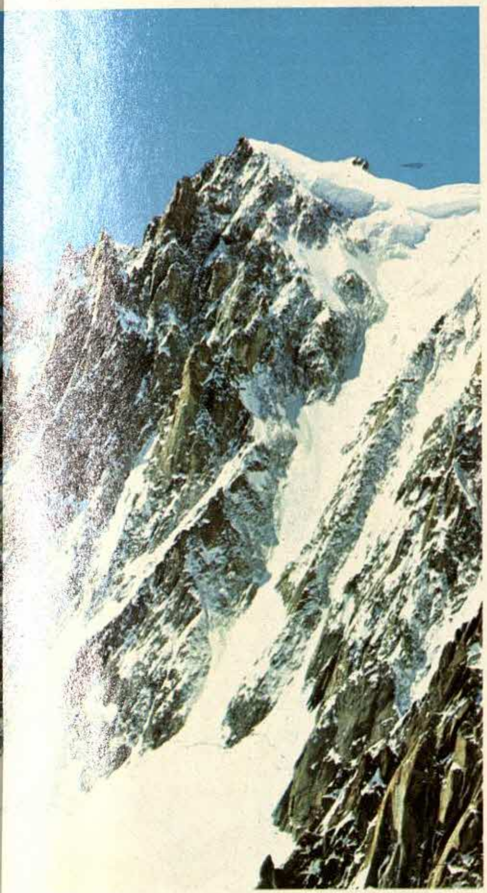
THE SLOPES FLANKING A GLACIAL VALLEY—The glaciers that sculpted most mountain valleys during the Pleistocene epoch of the Quaternary period (about two million years ago) produced characteristic features in these openings in the mountains. These glaciers had colossal dimensions, and some of them (for example, the glaciers that filled the Aosta and Tellina Valleys in Italy) had a thickness of about 2,000 m (about 6,500 ft).

If an excursion is made into mountains, especially into high mountains, where the sides of the valleys consist of rocks that are either bare or only very lightly covered by sedimentary deposits, and the observer puts himself into a position where the entire valley can be seen, he can readily observe its characteristic glacial form. This form, with its U-shaped profile, cylindrical bottom, and vertical walls, can be discerned in this photograph taken in the Tellina Valley in the Central Alps.

is static in this dynamic universe. Many times in the long course of the Earth's history, mountains have been thrust upward from the planet's crust, only to be worn down by the relentless forces of nature. The wearing down or erosion of mountains ordinarily proceeds so slowly that a man cannot perceive the changes in his lifetime. However, by careful observation of the forms of mountains, valleys, and undulating plains, scientists are able to reconstruct the history of the erosions that have shaped the face of the Earth.

The form or configuration of the part of the Earth's crust that is not covered by water is largely determined by erosion. Water and ice continually degrade the relief features of the Earth, wearing them down to level plains; the rate of erosion, quite naturally, is dependent on many factors, including the nature and hardness of the rocks and the volume and force of the water.

4



MOUNTAINS MADE OF IGNEOUS ROCKS—Igneous rocks are rocks that have been formed by the solidification of magma. Sometimes magma issues from volcanoes onto the surface of the Earth; such material is then called lava. Entire regions of the Earth are covered by lava to a thickness of several thousand meters. However, the rocks produced by the underground solidification of magma are even more numerous and frequent; these intrusive igneous rocks have been exposed subsequent to their formation as a result of orogenic uplifting and, later still, as a result of erosion.

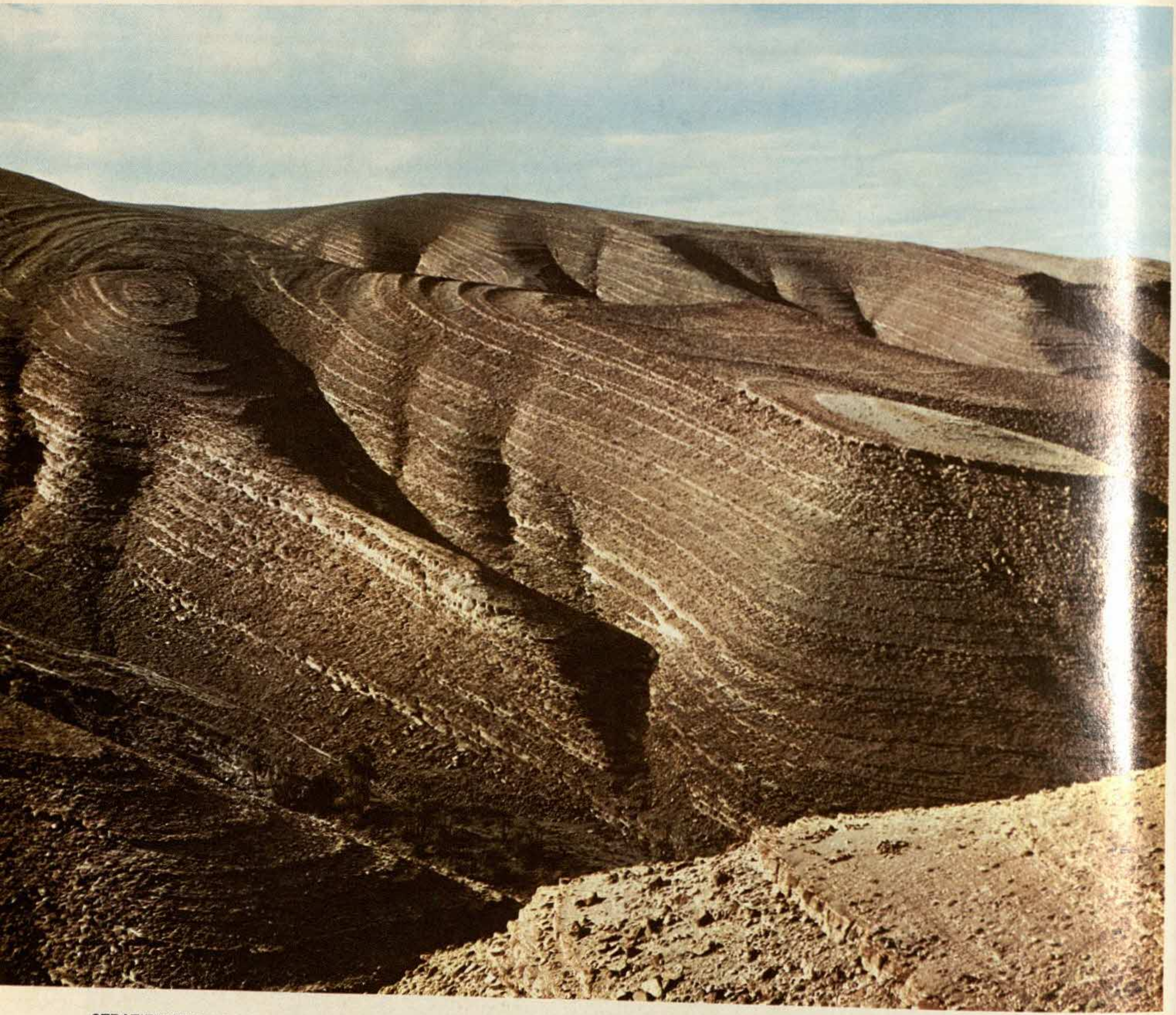
Igneous rocks are very homogeneous insofar as their structure is concerned. The solidification of these rocks, which was brought about by slow cooling, has produced characteristic fractures of the rock masses, which frequently appear to be subdivided into parallel blocks, often detached from one another. The forms of mountains constituting these rocks terminate with planes that are perpendicular to the planes of fracture.

The characteristic fractures and the corresponding mountain forms may be observed rather well, for example, on the Pizzo Badile in the Masino Valley, in the imposing Mont Blanc group.

5

OLD MOUNTAINS—All the mountains are old in comparison with the length of time that man has been on the Earth, but some mountains are much older than others. The Alps, Himalayas, Andes, and Rocky Mountains, for example, are all considered to be young mountains; their ages can be measured in terms of tens of millions of years. The Appalachian Mountains in the eastern part of the United States and the Ural Mountains in the Union of Soviet Socialist Republics are prime examples of old mountains. Young mountains can be recognized by their sharp, angular peaks, whereas older mountains can be distinguished by their soft shapes, gentle slopes, and rounded outlines. The appearance of the latter is typified by the Apennines, the hills of England, and the rolling countrysides of some regions in Africa (shown in the illustration). Other old mountain units are in present lowlands of Canada, Brazil, Siberia, and Fennoscandia (Baltic Shield), in areas that have been above sea level and subject to weathering and erosion through long ages.

6



STRATIFICATION AND SLOPE—The signs left by glacial erosion are not always visible in the mountains. In many cases they have been removed by subsequent weathering and erosion.

The rocks that have been formed by the consolidation of sediments deposited at the bottoms of seas or lakes (and subsequently uplifted) often are not homogeneous. In this photograph may be seen a truly spectacular example of stratification in the mountains of Morocco. In such cases the mountain structure usually consists of a succession of strata of different hardness. If the strata are arranged horizontally and contain rocks of varying degrees of hardness, differential erosion occurs, with the softer strata eroding more quickly than the harder strata. In time, as erosion continues, the harder strata are carved into relief, forming terraces. If the upper stratum consists of highly resistant rock, a mesa or a butte may be formed. In fairly arid regions such as Morocco and the southwestern part of the United States, erosion proceeds rapidly because precipitation (when it does occur) takes the form of torrential downpours. Providing clues to ancient environments, stratification is one of the geologist's most useful tools.

EROSION AND BUILDING OF COASTS

the sea as architect

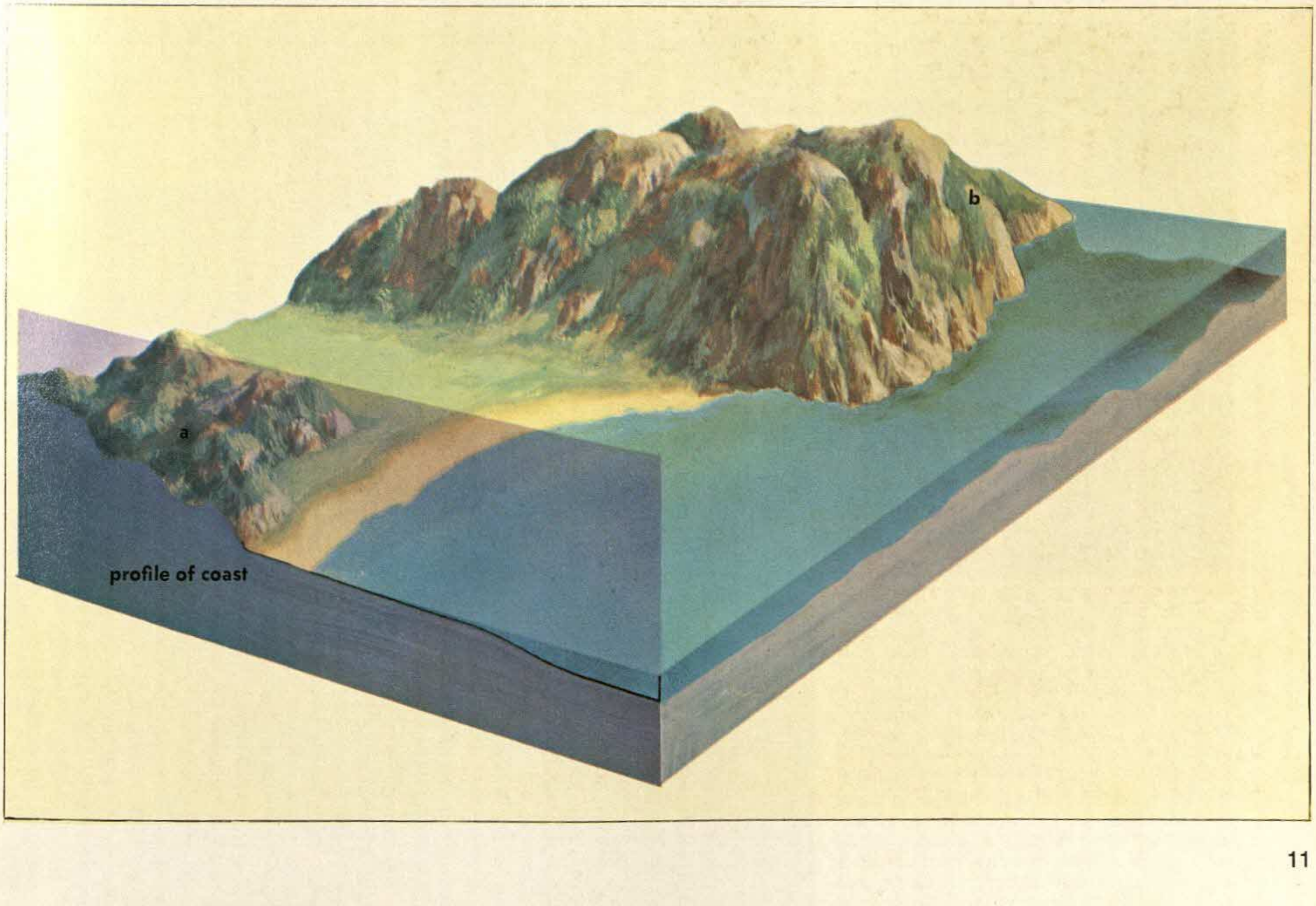
The waves of the sea affect various coasts in different ways—depending on the form of the coast. They may slowly erode it, or they may expand it. By observing the form of the coastline, scientists learn whether the sea is tearing it down or building it up.

Along the shore of the Adriatic Sea, from Aquileia down to Pesaro, are the remains of many cities that in ancient times were once seaports but are now well inland; one such city is Ravenna, now six miles from the sea. Along the northern coast of France, on the other hand, are many villages that are now much nearer to the sea than they were when they were settled; in some of them buildings have been destroyed because the land on which they stood was eroded away by the sea. There are reasons for these different effects: the receding action of the sea on certain coasts, where it continues to deposit considerable sand and gravel, extending the land; and the destructive advance of the sea against other coasts, where the rock is gradually eroded and removed by the sea.

PROFILE OF COAST AND CONTINENTAL SHELF—These phenomena are best understood by observing the features of coasts, and especially by distinguishing on sight the various possible profiles of coasts. (A profile, in this context, is the line that would be formed along the surface of the land from the coast through the shore and into the sea, if a vertical cut were made into a section of the coast at right angles to the coastline.)

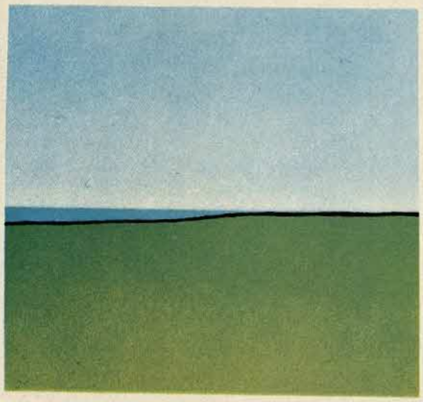
Observation of a coast profile must be conducted in two ways, involving the contours of the landward approach to the sea and also the characteristics of the adjacent ocean floor. The contours of the land can best be observed from a high point on the coast itself; from such a vantage point it can be noted whether the land rises steeply from the sea—as is often the case along a rocky coast—or whether it continues in a gentle slope from the continental shelf offshore. The submerged part of the profile is most easily observed by determining the depth of the water—not to the extent of measuring that depth—but merely to learn by observing the color of the sea whether it is deep or shallow. This may be observed either from a high point along the coast or, if there is no such point, by standing in a boat as it moves gradually away from shore for a few hundred yards. For good results, this observation requires a calm sea and water clear enough to allow the seabed to be seen.

The question to be resolved is whether the floor of the sea slopes gradually for the first half-mile or so away from the shoreline **a**, or whether it drops vertically or even steeply for a dozen fathoms or so and then continues seaward with very little slope **b.** If the slope of the seabed is gradual, the part near the shore will be predominantly composed of sand or fine gravel; if it drops steeply, however, the bed will consist of deposits of rather large boulders and sometimes of rock fragments with sharp, angular edges. Such edges indicate that the rocks have been split fairly recently from the rocky cliff (otherwise the rocks would have been rounded off by the action of the water).



2a

2b



WAVES, MARINE CURRENTS, AND TIDES—

The two principal types of coast just described—characterized by high, almost vertical cliffs or by a low and sandy shore—are usually designated as "young" or "old" coasts, respectively. These terms, when used to classify coasts, must be understood in a geological sense. The continents are known to be rising or subsiding over periods of geological time, at a rate of as much as a few inches a century. A rapidly rising (emerging) or subsiding (submerging) coast may have young topography (Illustrations 2c and 2d), whereas a coast that is relatively stable for long periods of time may be formed, through the destructive agents of the sea, into an old topography (Illustrations 2a and 2b). These destructive agents are the waves, the marine currents, and the tides.

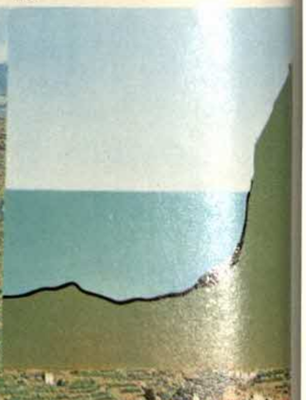
Waves move material along the seabed only at depths of less than 6 fathoms (36 ft). In such shallow waters, and especially along the shore, wave motion can distribute loose sediment, such as sand and gravel. The principal power of waves, however, is the violent hurling of water against rocky cliffs, detaching fragments and eventually eroding the entire coast. This power is so tremendous that large blocks of concrete weighing as much as 1,000 tons, placed near coasts and in harbors as parts of seawalls, have been thrust ashore by wave action. Waves also determine whether the sand is distributed along a beach or carried out to sea and deposited there.

Marine currents, the result of wind action and temperature differentials, can carry rock fragments as large as one-half inch in diameter for considerable distances. Currents with a velocity of several meters per second have been measured at depths of about 60 fathoms (360 ft)—for example, a current of 2 m per second (about 4½ mph) has been observed along the bed of the Straits of Messina. Such currents can transport loose material along the coast and deposit it on the sea floor, far from its point of origin. Tides can also develop currents that will transport loose material.

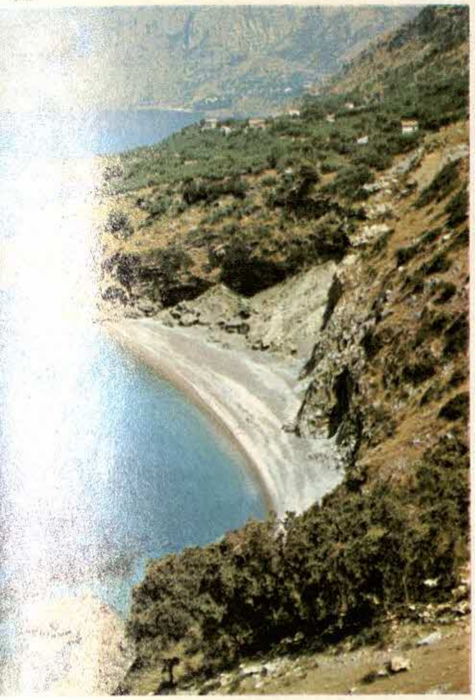
Another agency that influences the topography of coastlines, although it is not a marine agency, is the river; streams deposit a vast quantity of material—sand, silt, and gravel—in the sea. This sediment is then redistributed by the waves and currents, and may either accumulate along the coast or be carried to the open sea.

2c

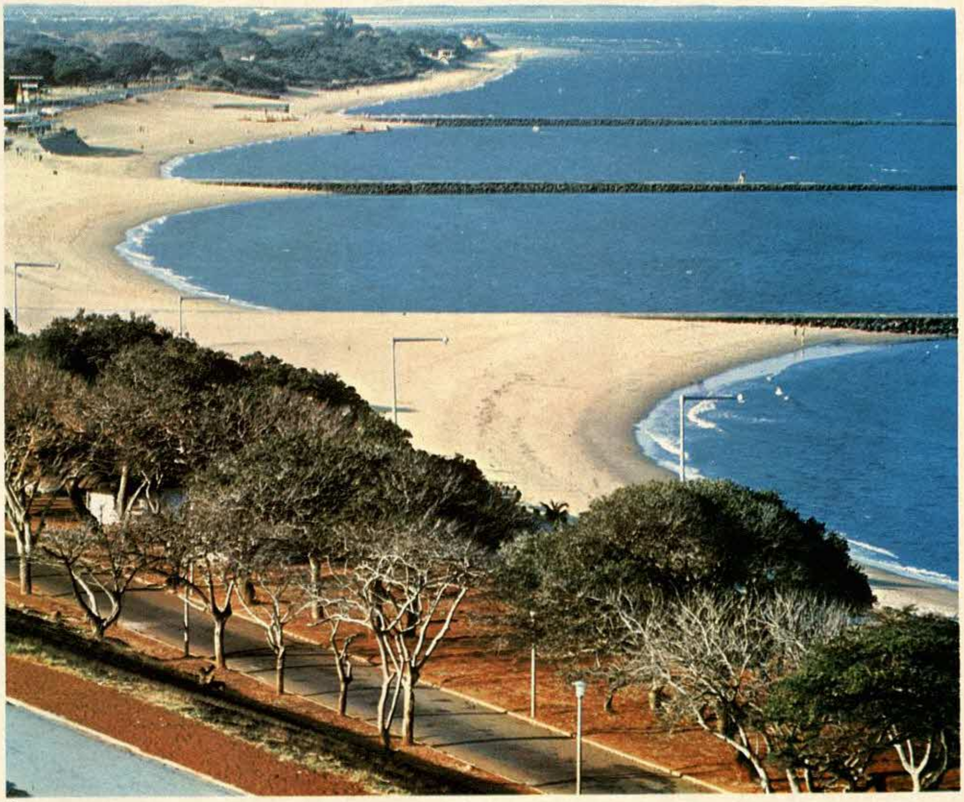
2d



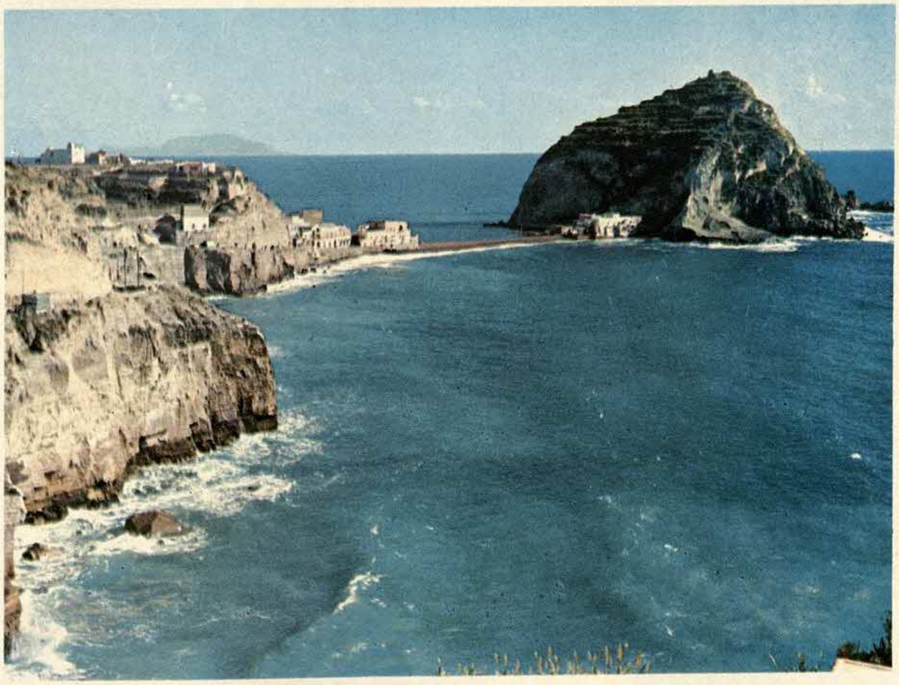
3a



3b



3c



EROSION OF COASTS—Illustration 3a shows a stretch of coast along which rocky promontories alternate with small crescent-shaped beaches. The waves tend to destroy the coast, but not uniformly; they wear down the promontories, which were probably once much higher, and deposit the eroded material along the nearby beaches. This deposition occurs because the waves, as a result of friction, tend to lose some of their force in the shallows between promontories, and cannot carry as much sediment. After an extensive period of depositing this sediment, the shore between promontories is sanded up. The total effect of the sea action, therefore, is the erosion and cutting back of high coasts and the filling in and advancing of low coasts. This effect is especially noticeable wherever the works of man interfere with the natural balance.

Breakwaters constructed along a stretch of beach, for example, tend to slow the motion of the waves, increase the deposition of sediment, and therefore extend the beach between two such breakwaters (Illustration 3b). In a similar manner, islands or rocks separated from the mainland by a narrow arm of the sea (Illustration 3c) tend to be joined to the main coast. A small island, especially one with young coasts, is subject to the erosive action of waves and is likely to be gradually destroyed. The eroded material is usually deposited wherever the motion of the waves is slowed—for example, in a narrow strait between the island and the mainland—first along a narrow bar making the shortest distance between the two land areas. The bar then expands to the crescent shape characteristic of sandy beaches. Illustration 3c shows a fine example of this kind of beach building at Sant' Angelo di Ischia, off the Italian coast near Naples.

A map will show how deposits accumulate at the mouth of a river, gradually extending the land to fill part of the sea. Such recently formed land is subject to the erosive action of waves and currents, which gradually wear off and transport material in the vicinity of the delta. In this way tongues of land are formed, separated by large areas of water, usually known as lagoons or, sometimes, lakes.

As a large river winds toward the sea through its delta, it must pass through these lagoons, and in doing so it loses some velocity and is less capable of transporting its load of sediment. This material is, therefore, deposited in the lagoons, and soon fills them. The lagoons near the city of Venice, shown in this map, were formed in the manner just described and tend to silt up; but the people of Venice have an interest in keeping their waterways open, and so they constantly drag the rivers that flow into the lagoons (to deepen the channels and slow down the deposition of silt) or divert the rivers away from the lagoons altogether (to prevent any deposition from taking place). However, even when lagoons are thus protected from stream deposits, they tend to silt up because waves and currents form sandbars between the sea and the lagoons. It is then necessary to open these bars by dredging, so that the tide can enter the lagoon and, as it leaves, drag part of the accumulated sediment away to the open sea. At the same time, a lagoon must be protected against storms and tidal waves. In the case of the Venetian lagoons, a dike protects the narrow sandbars that separate them from the open sea, which would otherwise surge over the bars and fill the lagoons with sand.

LARGE-SCALE SURVEYING

modern techniques of geological surveying

Geological surveying has undergone a rapid evolution during the past few years. Technological advances—especially the utilization of aerospace reconnaissance—have played a large part in this evolution, but are by no means the only factor. The age-old law of demand is evident in the ever-growing need for raw materials; the consumption of nickel, chrome, iron, zinc, and other metals has reached such levels that new deposits must be found. Another important influence on the evolution of geological surveying has been the search for newly discovered elements that, in earlier times, had no technological applications, but today are of the utmost importance.

Modern geophysical and geochemical techniques have been applied to mineral prospecting. The old method, whereby a geologist filled in details on a map after laboriously examining the terrain and collecting specimens, is no longer adequate. Despite recent advances, however, techniques of geological prospecting are still somewhat primitive. Geophysical methods of prospecting at great depths are applicable to only a few minerals. Iron is an example. A large deposit of iron ore can be localized even at a very great depth because it produces an irregularity in the Earth's magnetic field that can be detected by magnetometers even at a considerable distance. Thus, a map of the Earth's iron deposits—including those at great depths—can be accurately drawn; at what depth these can be economically exploited is quite another question.

Geophysics can also supply very complete data on oil deposits. The structure of strata buried deep below the Earth's surface can be determined, and, because oil is generally associated with certain structures, it is possible to deduce the likelihood of the presence of oil from the existence of an appropriate structure. The methods described apply only to the search for iron and oil.

Other methods of surveying and prospecting also apply only to specific minerals, usually found on or near the surface. Geochemical prospecting, a fairly recent development, is such a method. The region under investigation is divided by a grid; a ground sample is taken at each grid point and subjected to chemi-

URANIUM PROSPECTING—Until recently, the search for uranium was carried out by rather rudimentary means. The prospector walked over the ground, carrying a scintillation counter connected to a device for measuring the count of the received pulses of the uranium. Wherever the number of pulses rose to an abnormal level, a sample for analysis in the laboratory was taken. From these analyses and the prospector's observations, a map was constructed.

This system left much to be desired. It was slow and tedious, and involved inevitable inaccuracies inherent in the method of obtaining data on radioactivity. Not all radioactivity emitted by rocks is attributable to useful concentrations of uranium. Furthermore, the pulses supplied by the counter that has measured the radioactivity of the uranium are supplemented by pulses due to cosmic rays or to the radioactivity of thorium, samarium, or potassium.

The need to intensify the search for uranium has led to refinements in this method. It is essential to extend the prospecting to areas where there is a low level of radioactivity. Where a rock of low radioactivity covers a vast area and its central part is found to be much richer in uranium than other parts, it is probable that this rock covers an exploitable uranium deposit—one that is invisible to the prospector, who may note a small irregularity in radioactivity but will find it materially impossible to prospect the whole area.

A much faster and more accurate method is employed today. An airplane carrying a radioactivity detector takes continuous measurements while flying over a certain area. The data are recorded on a magnetic tape, together with the coordinates of the point at which each measurement was obtained. These data are recorded in such a way that it is possible to distinguish radioactivity due to uranium from that caused by thorium or other elements.

The magnetic tape is then analyzed by a computer, and the output is automatically plotted, producing a map of the surveyed area that indicates the locations of uranium concentrations.

Illustration 1a shows the track of the search airplane, which flies at an altitude of a few hundred meters. At higher altitudes, the atmosphere screens the radiations and gradually weakens them; furthermore, an excessive altitude would reduce the accuracy of the measurements because the detector would record radiations from too extensive an area.

Inside the airplane (Illustration 1b) are seven large scintillating crystals that serve to convert gamma rays into a light signal. Six of the crystals are aimed toward the ground and, insofar as possible, are screened against cosmic radiation. The seventh crystal detects only cosmic radiation. Each measurement by the six counters yields a number of pulses per minute; this is reduced by the number measured by the cosmic radiation counter.

The sensitivity of the scintillation counters depends on their volume. Their diameter is about 40 cm (about 15 in.) and their thickness about 10 cm (about 4 in.). They are made of sodium iodide activated with thallium, making them far more sensitive than very large counters made of plastic material.

Each scintillator is connected to a photomultiplier that transforms the radioactivity signal passing through the crystal into an electric pulse. Each measurement channel has a preamplifier to form and strengthen the pulse. The signal coming from the channel is recorded as a codified number that can be read by a computer; the number corresponds to the amplitude of the pulse, proportional to the energy of the ray that has caused it. Thus, the nature of the radioactive element that produced the radiation is measured. The abundance of the numbers recorded on the tape corresponds to the abundance of the element in the ground.

While the aircraft is in flight, three radio beams on the ground (**A, B,** and **C** in Illustration 1a) indicate the reference position and deduce its coordinates. Two radiogoniometers on the aircraft indicate the angle of the radio beams as a codified number to be subsequently read by the computer.

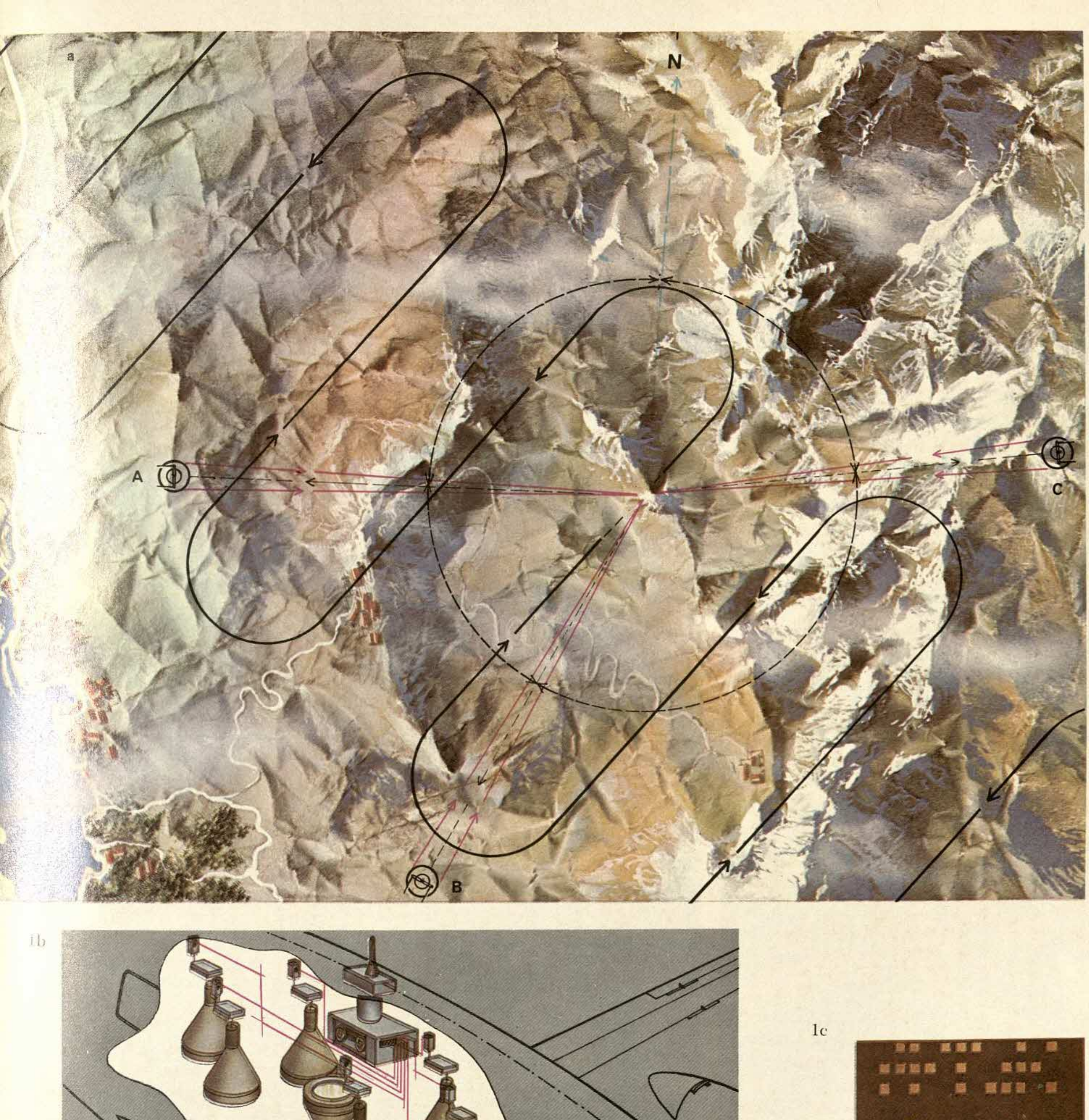
Illustration 1c is an example of the data recorded on the magnetic tape. The first pair of numbers indicates the position of the aircraft; the next block indicates the measured pulses; lastly, a code identifies the counter that gave the pulse.

This tape subsequently serves as input for the computer on the ground. The computer performs a number of functions: it subtracts the number of pulses counted by the cosmic radiation detector from each group of numbers ("cleaning" the data on the tape); and it puts pulses of different amplitude into different memory cells, making it possible to ignore pulses due to elements other than uranium. The computer then correlates the data with the coordinates of the point where they were obtained, transforming the angles recorded by the radiogoniometers into measurements of terrestrial coordinates relating to the explored area. Finally, the computer interprets these data to obtain the information needed to plot the curves of radioactivity.

Illustration 1d shows a plotter—an apparatus that moves a pencil over a piece of paper on receipt of a digital command. The plotter records the curves of equal activity over the explored area, providing a drawing that is relatively easy to interpret.

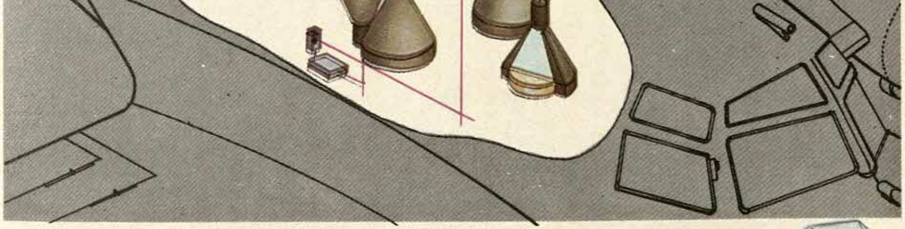
The survey is completed by ground prospecting teams who explore in detail those areas enclosed by areas of high radioactivity. Since only the most likely areas as indicated by the preliminary surveys need be explored, trenches can be excavated to measure radon emanations (an index of the presence of radioactive materials even at great depths) and trial borings can be made. This is no longer large-scale surveying, but detailed prospecting guided by a large-scale survey, the cost of which is far less than that of the older methods.

Still, despite the highly efficient methods employed, the techniques of uranium prospecting are still limited, and minerals at a depth of several thousand meters are likely to remain undiscovered for some time. Further refinements in geological prospecting can be expected.

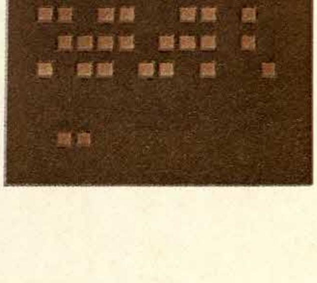


1a

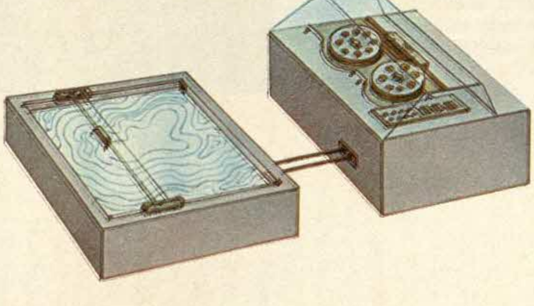
1b



1c



1d



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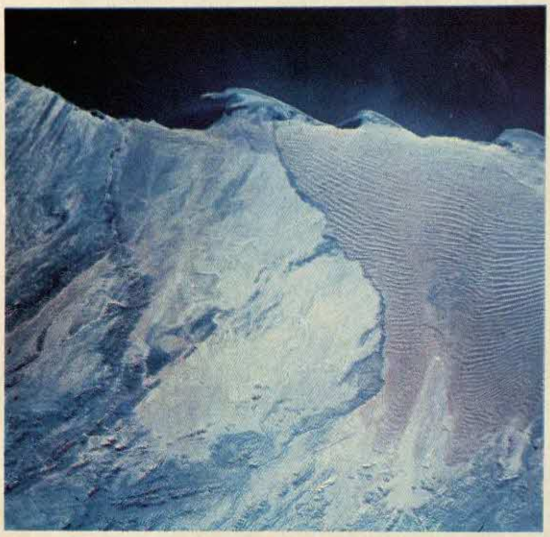
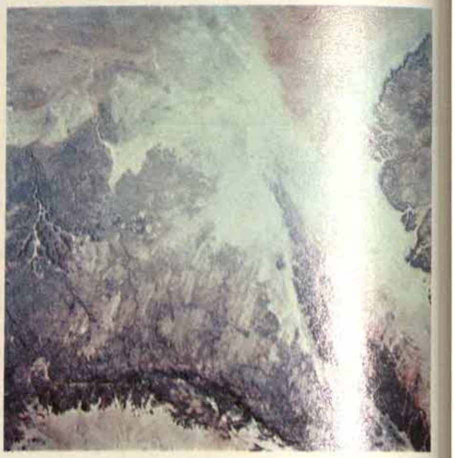


A SEA OF SAND—This photograph makes possible reconstruction of the underground hydrology of the area. Some flat areas are characterized by the presence of red Sahara sand; another area in the photograph shows rocky hills. The courses of some surface rivers whose beds are dry because of the season can be seen. Infrared photographs, using a particular wavelength that reveals the thermal balance of each section of the ground, are used to locate undeground watercourses.

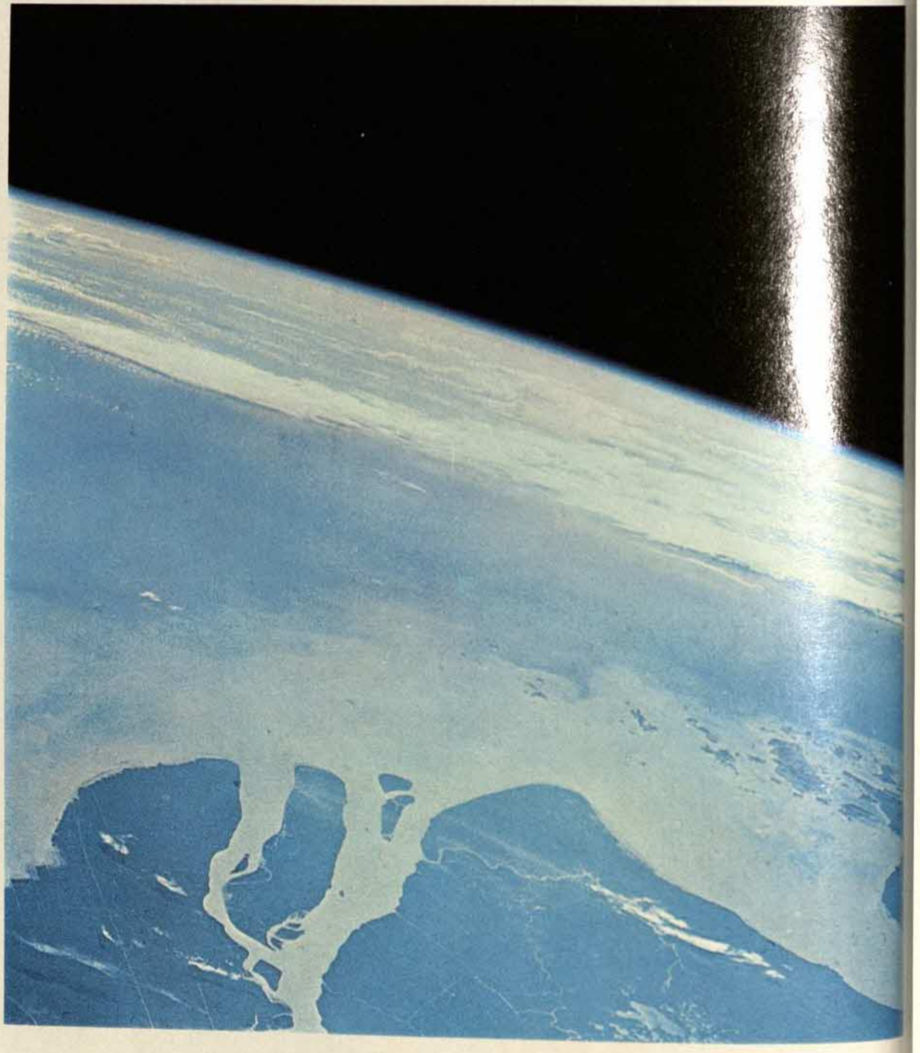
3



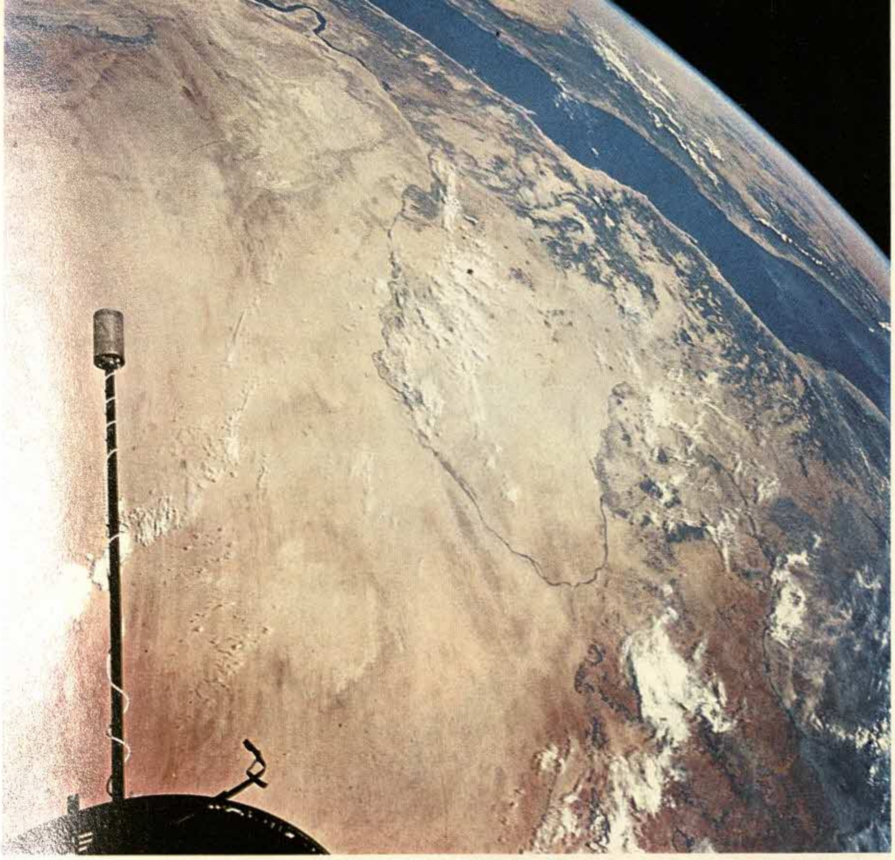
SURVEY BY ARTIFICIAL SATELLITE—At present it is not possible for satellites to detect magnetic or gravitational irregularities except where these affect very vast areas. However, photographs taken from a great height provide much useful information. Because the atmosphere is almost free of haze at altitudes between 15 and 150 to 250 km (about 9 and 93 to 155 mi); very detailed images can be obtained from the altitude at which a satellite orbits.

The photographs on this and the following page were taken from a manned Gemini capsule; similar results can be obtained by unmanned satellites. Illustration 2 is a coastal region of southeast Africa; the extent of the sand dunes can be determined, surface hydrology reconstructed, and a number of faults located. Such a survey by satellite is far more rapid than a corresponding survey by means of aerial photography. A survey made from the ground would take infinitely longer.

4



THE SEDIMENT OF THE YANGTZE—A single photograph embraces the entire area of the sea in which the Yangtze River, famous for the enormous quantities of material dragged along by its waters, deposits its silts. A photograph taken from vertically above rather than at the oblique angle shown here would accurately define the overall sedimentation area and also the areas in which various amounts of material are deposited.

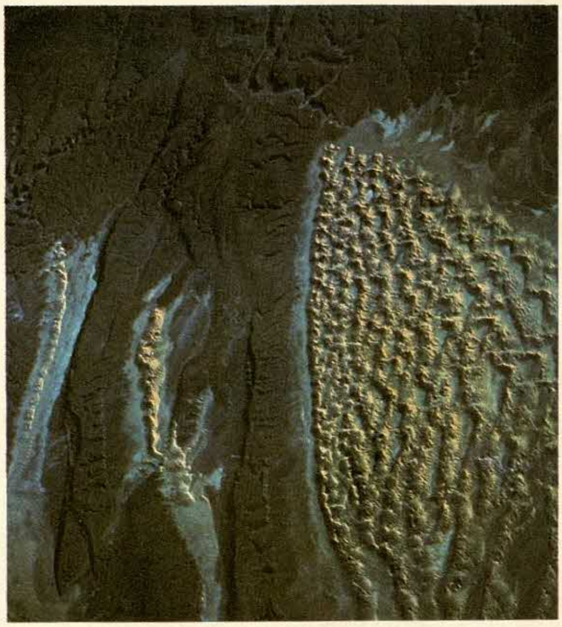


5

THE COURSE OF THE NILE—This photograph shows the whole of upper Egypt and the course of the Nile. The river can be seen clearly, along with the green area that lines its banks in the lower reaches. The various colors of the Egyptian desert are caused by imperceptible variations in the chemical composition of the sand, due to both the decomposition of different types of rocks and the different underlying formations.

THE ALGERIAN SAND DUNES—This photograph, taken at dusk, is a striking view of Algerian sand dunes standing out in relief from the ground because of the angle of light. These dunes reach heights of 300 m (about 1,000 ft). The sand dunes contrast with the adjacent hilly region; the morphology of the hills allows an accurate description of the area once the photograph has been correlated with ground observations.

6



cal analysis. This analysis is not particularly concerned with the principal elements contained in the sample (usually, silicon, calcium, carbon, and such metals as aluminum and iron) but rather with those elements of which only traces are present. An abundance of certain of these elements can furnish a guide to the localization of a concentration that is exploitable.

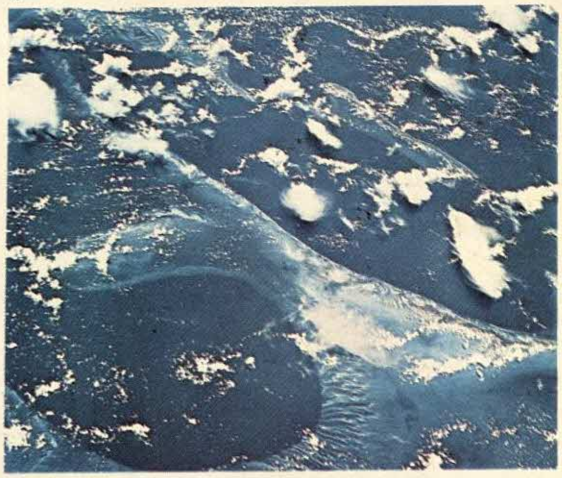
Another method used in the search for specific elements is electrical prospecting. A current is passed through the ground and its flow lines are determined. The observation of pronounced variations in conductivity indicates the presence of certain elements.

A geological map of a region generally supplies useful indications about the nature of the ground and some preliminary information about the minerals that might be found there. Further search allows compilation of a more detailed geological map; the survey may then be implemented by explorations of the ground at shallow depths. In some cases it may be advisable to excavate a few exploratory shafts when surface veins provide some clue to the composition of the ground at a greater depth.

Knowledge of the possible world reserves of some important elements is only tentative and superficial. Uranium is an example. Because uranium is radioactive, it can be found with the help of a scintillation counter. However, the radioactivity of uranium is only perceptible at relatively shallow depths. The need for more thorough knowledge of the availability of this extremely important element has led to the development of large-scale methods of surveying that obtain results in a minimum of time.

Artificial satellites permit a rapid reconnaisance of the ground and supply photographs of sufficient detail to direct further search. As more sophisticated instruments are developed, these satellites will be able to make far more detailed analysis of the ground than can be done through morphology; and effects on prospecting will be far-reaching.

7



OCEAN BANKS AND DITCHES—The study of continental shelves is especially important in oil prospecting. This photograph highlights the submarine banks in the area of the Bahamas; a deep ditch can be seen at center and at bottom left. The form of the continental shelf can be readily determined by photographs taken from space. In oil prospecting, areas suitable for seismic surveys must be determined, and it is important to locate ancient river channels that were submerged by seas after glacial periods. Photographs such as this make the job far easier than the long and costly surveys carried out by sounding and mapping.

ROCK COLLECTING

some types of sedimentary rocks

To the uninitiated, rock collecting may not seem a particularly fascinating matter. Unlike minerals, most rocks resemble each other and are unlikely to arouse much interest. However, the study and analysis of rocks and their history can bring an understanding of the geology and evolution of the Earth's crust—and therein lies the fascination of rock collecting.

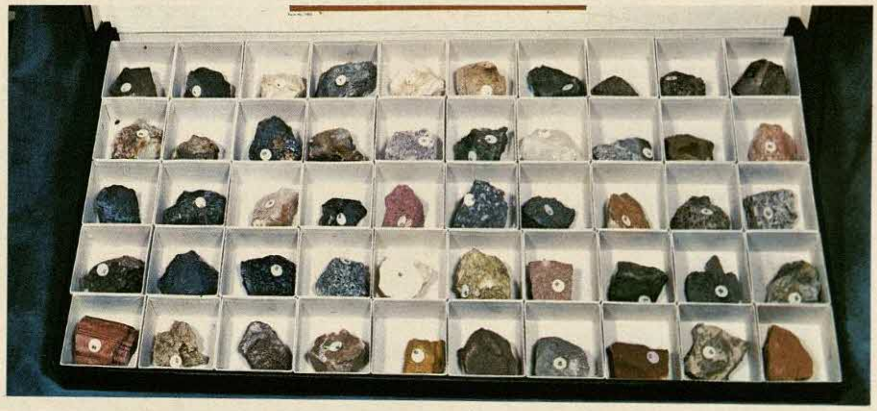
Well-formed mineral crystals are not common, but clearly recognizable rocks suitable for collecting are widespread. With a few exceptions, it is not necessary to identify a rock with a specific locality. A geological chart indicates that a specific rock is usually distributed over a wide area.

Some techniques are common to the collecting of both rocks and minerals. The sample should be collected where the material is fresh—that is, away from the action of atmospheric agents that might alter it, decompose it, transform it chemically, or tend to make it fragile and powdery.

The best rock sample is of a size that

THE ROCK COLLECTION—Each rock in this collection bears a number that serves to identify it in a log that contains a complete description of the rock and the locality where it was found. Generally, it is preferable to collect samples larger than those shown here and to put cards with complete data directly with them. For purposes of trading with other collectors, most collectors acquire more rocks than are necessary for study and display.

1



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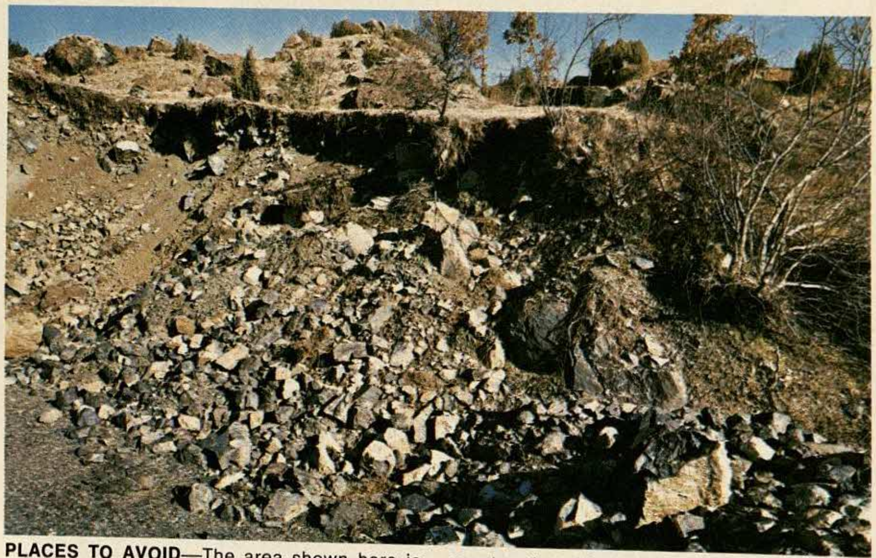
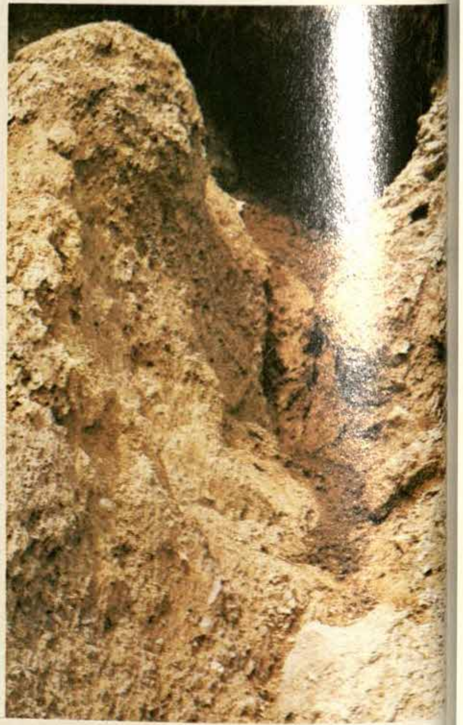


PLACES TO AVOID—The area shown here is not likely to produce good rock samples. Although outcroppings of rock are visible through the fragments, rubbish, and humus that cover the ground, they appear to be altered. A more likely location would be a construction site or road-building project where fresh rocks have been recently exposed. Even in areas that have only recently been excavated, however, it is advisable to break open a sample rock to see if its exterior surfaces are as fresh as those exposed on the inside.

ALTERATIONS TO AVOID—This rock has been exposed to the elements for a long time and has been completely altered by atmospheric action. It is being transformed into a type of clay or kaolin; at certain points oxidation has rusted the iron present in the rock and separated it in the form of rust-colored dust.

Such a sample would have little interest for the collector except as an example of the surface alteration of a rock to the extent that it is no longer recognizable.

3



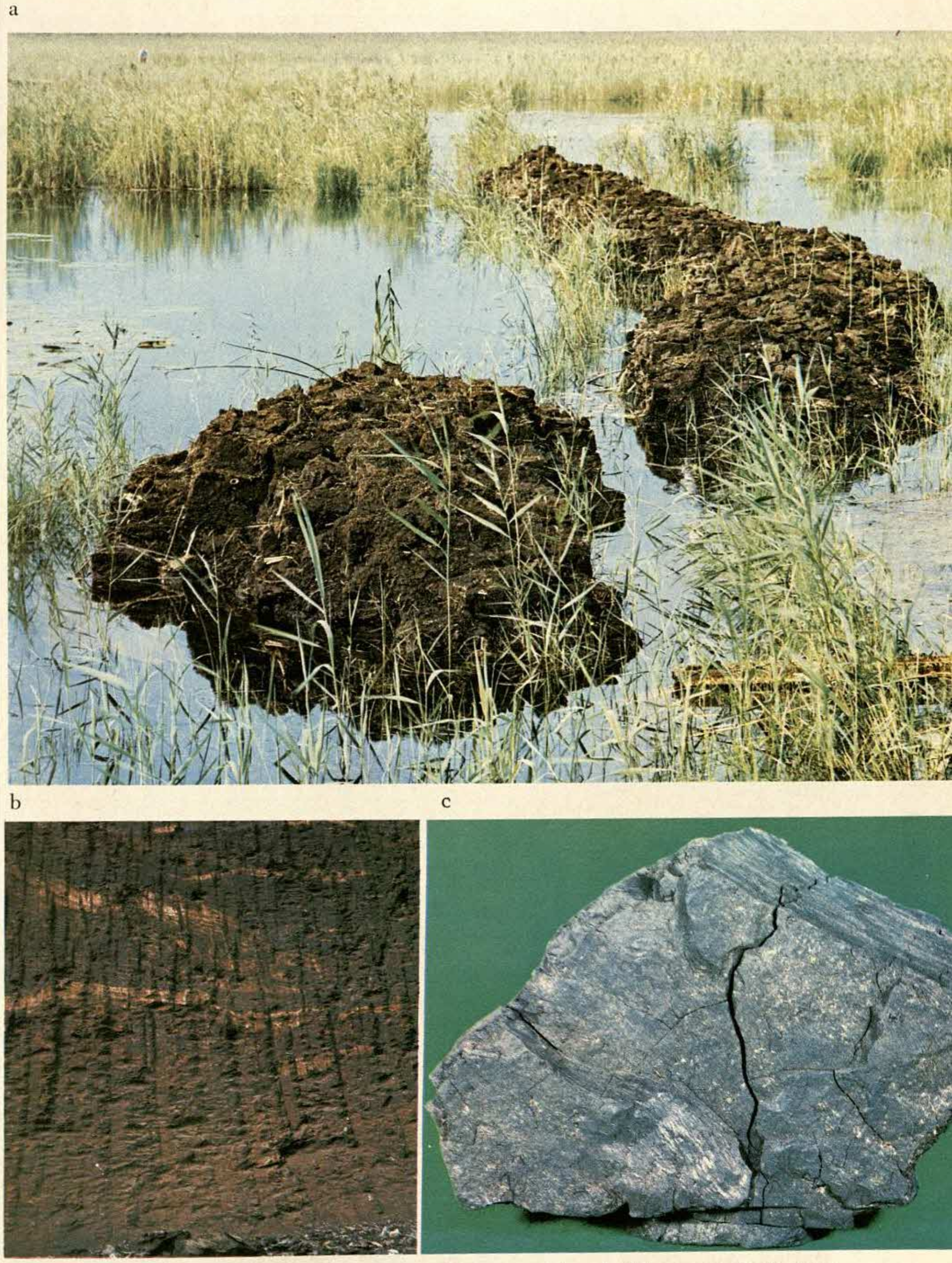
can be easily handled—about 5 by 10 by 15 cm (about 2 by 4 by 6 in.), for example. If a rock has clear fracture lines, the surface of the parallelepiped that corresponds to the rectangle 10 by 15 cm should be that parallel to the direction of the schist or fracture. The other two directions will be perpendicular to this. Samples should be taken with a geologist's hammer.

To avoid the possibility of confusing it with others, the sample should be placed in a plastic bag together with a card indicating the locality where it was found and its position.

This chapter deals with the collection of coal samples and other types of recently formed sedimentary rocks.

To the collector, the first indication concerning the nature of his rock specimen comes from familiarity with the geological conditions in the region where it was found. Areas are few in which all types of rocks are represented, and the collector's variety will be sorely limited if he is unable to visit regions apart from his home territory. Except for glacial boulders, the U.S. collector in the Midwest will be limited to sedimentary rock; indeed, much of the North American continent is covered by sedimentary rocks, now raised from the sea floor where they were put down on top of the older crystalline rocks. The distinctive property of most sedimentary rocks is their stratification; in fact, the term "stratified rock" is almost synonymous with sedimentary rock. From the manner of their formation by deposition in mud flats, on the shores, or on the floor of the sea, sedimentary rocks are likely to enclose fossils and markings that become part of the rock when the sediments harden. Besides animal and plant remains, the rock may preserve as surface irregularities the ripple marks of waves and the dents made by rain. Fossils are best known in shales and limestones. Recent sediments of the west coast are rich in fossils.

4



THE GENESIS OF COAL—Coal can be considered a rock of organic origin. The history of its formation can be traced by determining where it was formed and searching for the oldest samples to be found in surface and underground mines where deposits are progressively older. The story of coal begins with the deposit of vegetable debris that has decomposed and been reduced to a mass that has lost its water and is rich in carbon. The first stage of this process—peat formation—lasts a few months or years. Illustration 4a shows a peat bog. In this swamp, dead plants accumulate on the bottom, forming layers of vegetable material that decomposes in an airless place to form peat. The major portion of coal of the Quaternary period is peat.

Coal of the Tertiary period is more compact; it was not formed by swamp plants but by trees in thick layers. This form of coal is lignite, and is about 70 million years old. The sample shown in Illustration 4b shows the alternation of lignite layers with clay and other inorganic sediment. Illustration 4c is a sample of lignite.

d

e

Because it is impaired by inorganic residues, lignite lacks the caloric power of older coals.

Illustration 4d is a sample of bituminous coal, which has a greater carbon content and less volatile substances than lignite. Bituminous coal dates to the Mesozoic era.

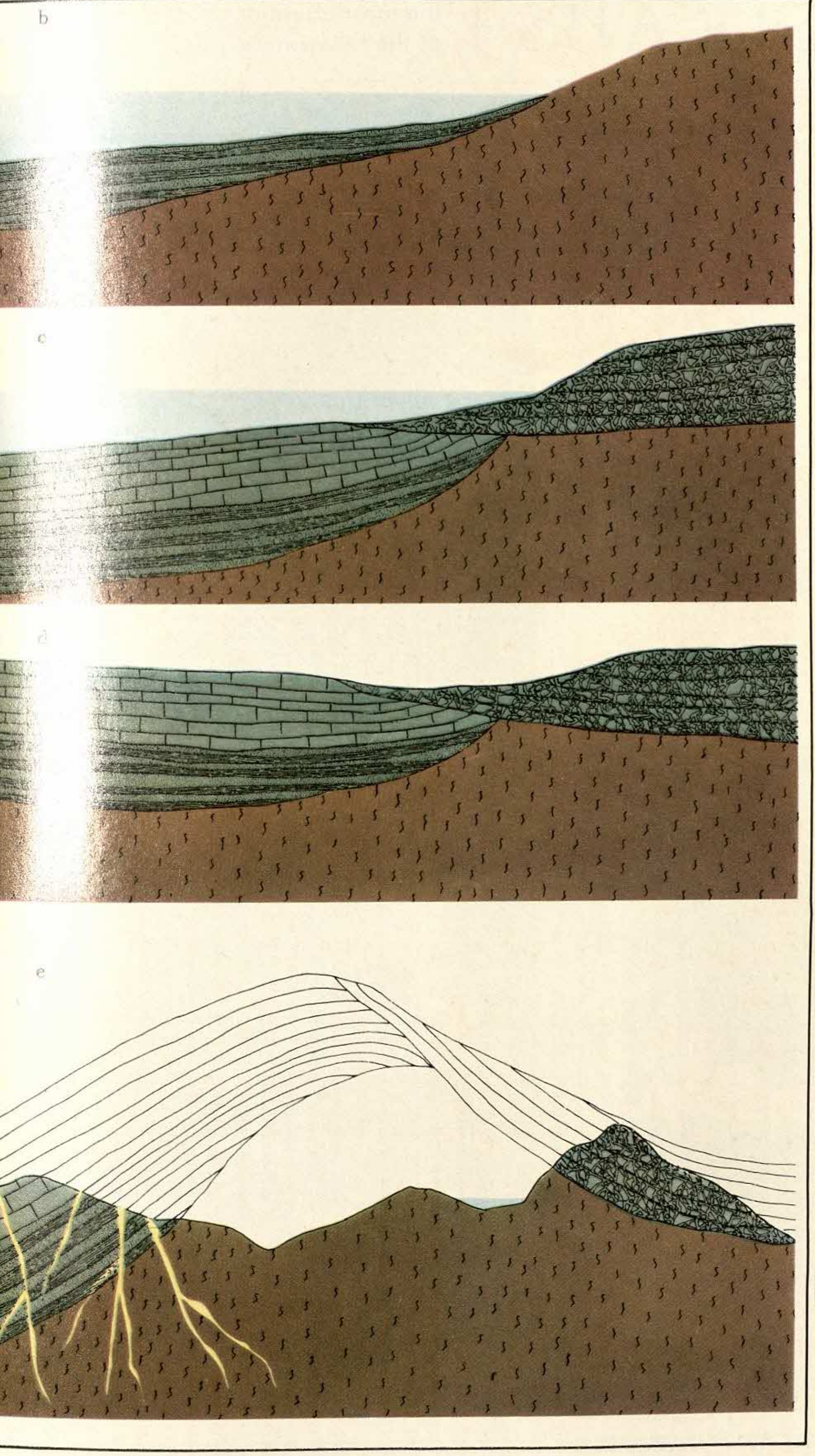
Anthracite (Illustration 4e) is coal of the Paleozoic era, generally of the Pennsylvanian and Mississipian periods. Anthracite and bituminous coals are difficult to find on the surface; they are generally buried deep in the ground. Some museums contain interesting samples such as this huge block (Illustration 4f), which weighs 2,330 kg (about 5,100 lbs). Despite its extreme age, it exhibits characteristic stratification and some imprints of its original vegetable form.

f

5

a

THE BIRTH OF SEDIMENTARY ROCKS—Illustration 5a shows a quarry of marl and marly limestone. These clearly stratified rocks were formed by the deposit on the sea bottom of sediment composed of small particles of eroded material washed into the sea. Small grains of common sand are the origin of sandstone; even smaller particles are the origin of marly limestone. Illustration 5b is a cross section of the sea bottom on which sedimentary deposits are beginning to form. Marine transgression caused the formation of alternate layers of very fine sand and clay on a rocky substratum; alternation was due to short sedimentary cycles. Periods of drought alternated with periods of floods; periodic winds caused high seas and the movement of the sea bottom, and variations in wind intensity gave a different motion to the marine currents and agitated the sea bottom, shifting the deposits. Illustration 5c shows what happened after a short period of such activity. The sedimentation continued, but geological phenomena caused a change in the material being deposited. The original material was covered by another thick stratum of different sediment, giving rise to another rock formation (Illustration 5d). The rock that initially remained underground was subjected to enormous pressure from the weight of all the material that accumulated above it. Thus this rock, washed by the water and under great pressure, began the process of recrystallization. The process was very much advanced (Illustration 5e) and was accompanied, over a long period of time, by folding and erosion, destroying much of the geology of the epoch through folding, breaking, and metamorphosis. Other rocks, which have just begun the initial phase of crystallization, have simply become cemented together; these rocks have undergone a minimum of alteration.



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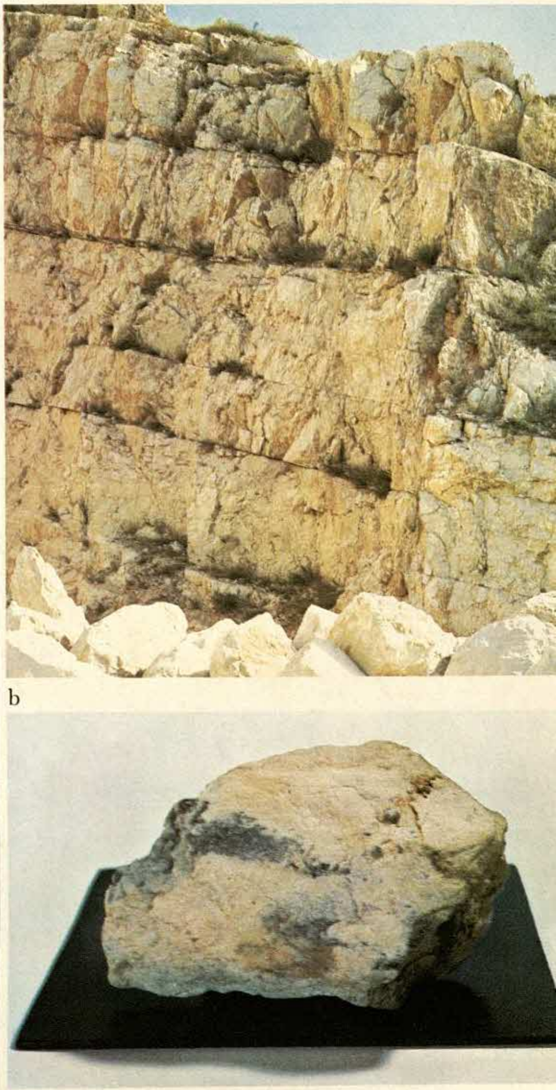


RECENTLY METAMORPHOSED ROCKS—Illustration 6a shows a quarry of compact limestone. This stone, like the marl and marly limestone shown previously, is a recently deposited and scarcely altered material.

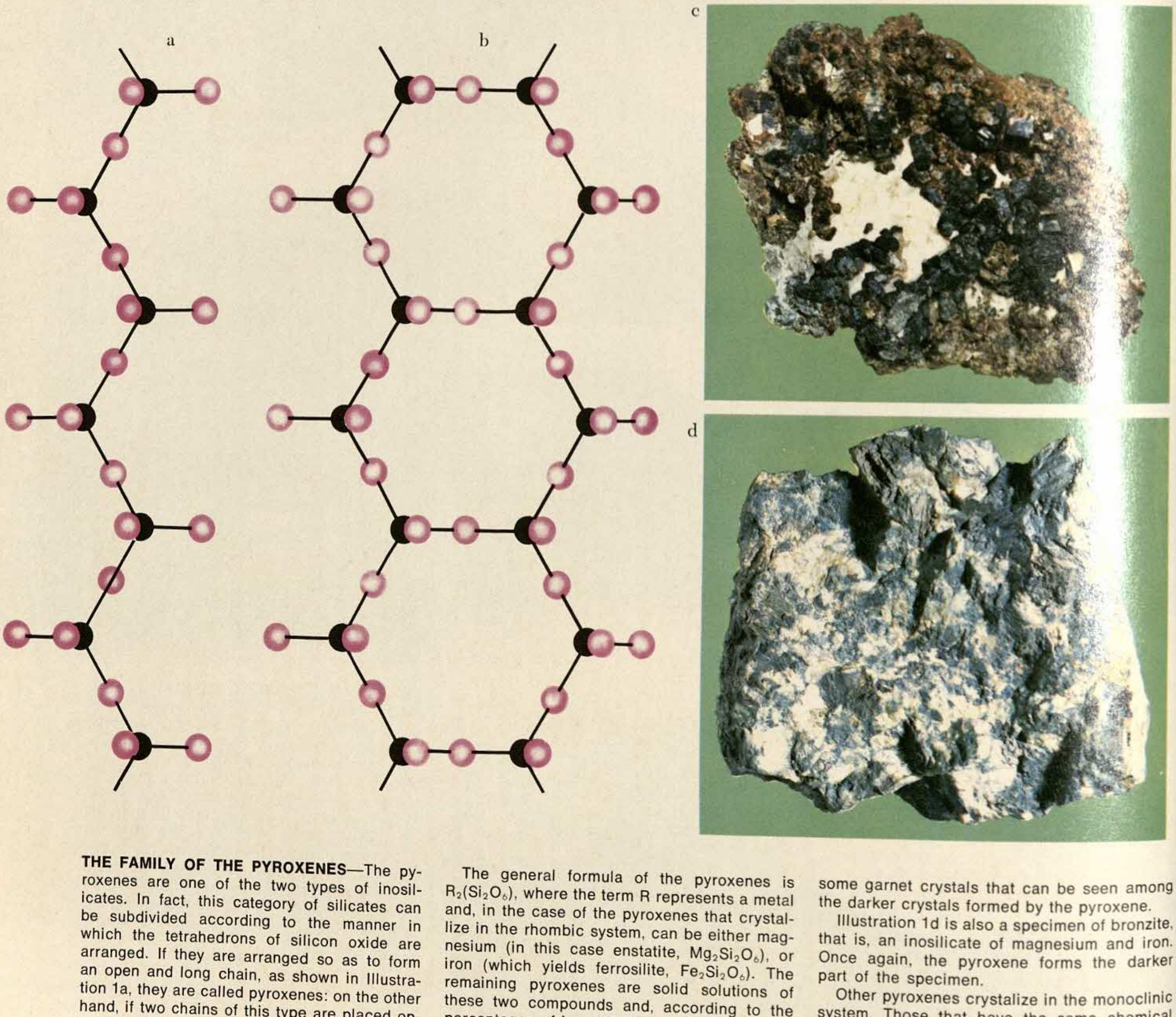
Illustration 6b is a sample of dolomite, a carbonate of calcium and magnesium whose crystallization can be seen in the photograph. The visible crystals of this rock are not those of particles originally deposited on the ocean floor, but are the faces of crystals that were completely transformed in successive alterations of the rock. It can be deduced that the rock has undergone profound changes over a long period of time.

INOSILICATES, PHYLLOSILICATES, AND TECTOSILICATES

the most abundant constituents of the lithosphere

The various categories of silicates are among the more interesting of the most important minerals that constitute the crust of the Earth. The silicates are subdivided into inosilicates, phyllosilicates, and tectosilicates. Except for very rare specimens, these minerals do not form very beautiful or highly pure crystals that could serve for oramental purposes. Therefore, finding specimens that are true gems is rare, the hope being rather to find crystals of large dimensions possessing nearly perfect forms. However, outstanding specimens of most silicates are not uncommon.

1



THE FAMILY OF THE PYROXENES—The pyroxenes are one of the two types of inosilicates. In fact, this category of silicates can be subdivided according to the manner in which the tetrahedrons of silicon oxide are arranged. If they are arranged so as to form an open and long chain, as shown in Illustration 1a, they are called pyroxenes: on the other hand, if two chains of this type are placed opposite each other and are firmly linked by means of oxygen bridges (Illustration 1b) the result is the double chain characteristic of the amphiboles.

The general formula of the pyroxenes is $R_2(Si_2O_6)$, where the term R represents a metal and, in the case of the pyroxenes that crystallize in the rhombic system, can be either magnesium (in this case enstatite, $Mg_2Si_2O_6$), or iron (which yields ferrosilite, $Fe_2Si_2O_6$). The remaining pyroxenes are solid solutions of these two compounds and, according to the percentages of iron and magnesium contained in them, are known either as bronzite or hypersthene. The specimen in Illustration 1c is an example of bronzite, of interest because it also contains other types of minerals, including some garnet crystals that can be seen among the darker crystals formed by the pyroxene.

Illustration 1d is also a specimen of bronzite, that is, an inosilicate of magnesium and iron. Once again, the pyroxene forms the darker part of the specimen.

Other pyroxenes crystalize in the monoclinic system. Those that have the same chemical formula as their rhombic counterparts are known as clinoenstatite, clinoferrosilite, and clinohypersthene. Other important monoclinic pyroxenes are jadeite ($NaAlSi_2O_6$), spodumene ($LiAlSi_2O_6$), and acmite ($NaFeSi_2O_6$).

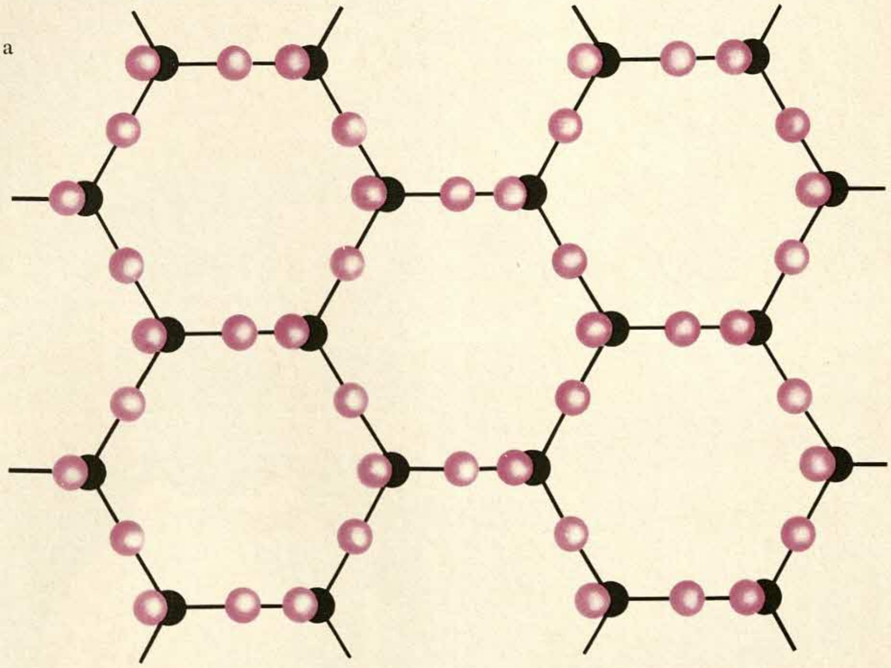
2

PHYLLOSILICATES AND MICAS — The name phyllosilicates is derived from the foliated structure of the crystals. The crystals of SiO_4 (Illustration 2a) are arranged in a manner that forms layers made up of a hexagonal mesh. This peculiar structure ensures that each foil, or layer, has a good mechanical resistance, but the bond between two adjacent foils is rather weak. Therefore, the phyllosilicates are characterized by the fact that they cleave very easily; this property is particularly characteristic of the micas.

There are three principal types of mica: muscovite, biotite, and lepidolite. Muscovite contains potassium and aluminum. Biotite contains potassium, iron, and magnesium. Lepidolite (much rarer than the other two) contains potassium, lithium, and aluminum. Biotite is characterized by a dark color, while muscovite and lepidolite are much lighter in color. Other micas are known by various names according to the elements they contain. Illustration 2b is a biotite having the generic formula $K(Mg,Fe)_3[(OH_2)AlSi_3O_{10}]$, which is a variety of mica commonly found in the pegmatites, whenever the pegmatites are close to igneous rocks that were formed at a depth of a few kilometers. Muscovite, on the other hand, is found in pegmatites formed nearer the surface and has not, therefore, had any need for contact transformations.

Illustration 2c is another specimen of biotite — a type that can be found, for example, in southern Italy, especially in the volcanic areas near Rome and Naples. Biotite, moreover, is one of the fundamental constituents of granites, and can be readily observed in the famous Baveno granites in Italy. Specimens of muscovite are common in pegmatites.

a



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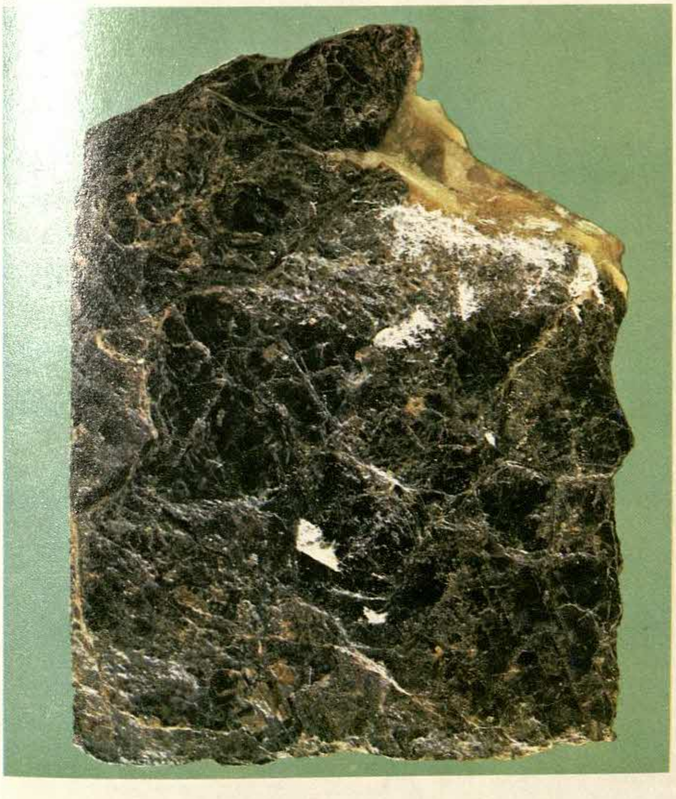
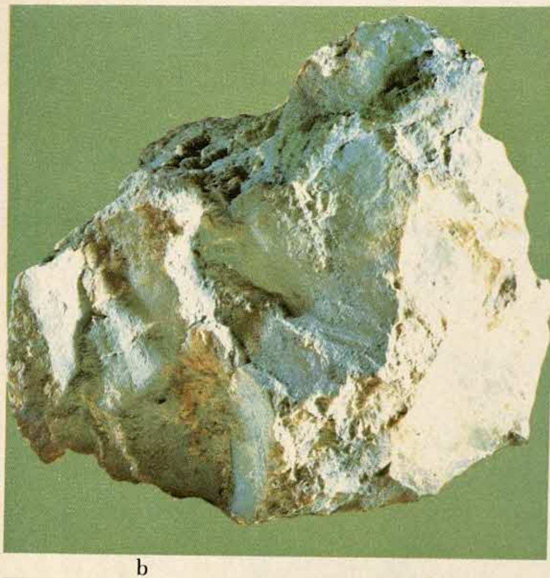


c

3

a



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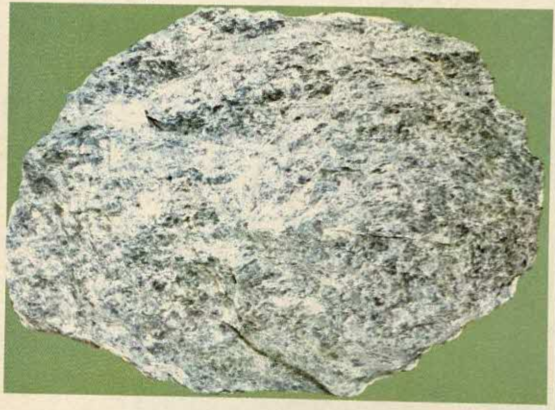


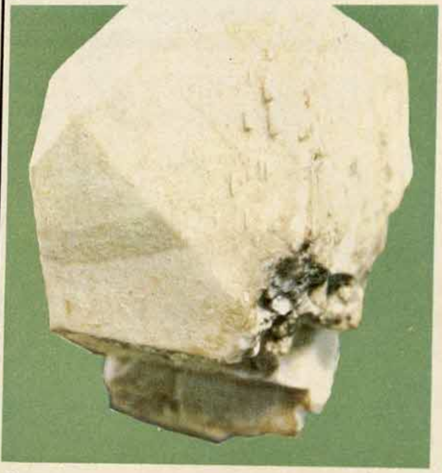
THE PHYLLOSILICATES OF THE SERPENTINE SUBGROUP—The family of phyllosilicates can be subdivided into many groups, one of which is the mica group. Another group is divided into two subgroups: the kaolinites and the serpentines, both extremely important minerals. These are two specimens of phyllosilicates of the serpentine subgroup. Illustration 3a is a block of garnierite, $(Ni,Mg)_6[(OH_6 \cdot Si_4O_{11}] \cdot H_2O$, which is included among the chrysolites, or fibrous serpentines. This mineral is particularly interesting because nickel forms part of its structure; other chrysolites contain iron, manganese, zinc, and aluminum.

Illustration 3b is a specimen of antigorite, $Mg_6(OH)_8Si_4O_{10}$, also known as laminar serpentine because it cleaves quite readily. Antigorite feels rather oily to the touch. Both garnierite and antigorite are formed by alteration of peridoditic rocks at considerable depths. This transformation required prolonged heating to temperatures in excess of 500° C (932° F). Types of these specimens are fairly common.

4

THE MOST COMMON SILICATES—About 60 percent of the total mass of igneous rock in the Earth's crust consists of a family of silicates called the feldspars, which belongs to the tectosilicates. Because igneous rock accounts for almost the whole of the Earth's crust, these crystals are extremely abundant. Nevertheless, good specimens are comparatively rare because feldspar is present only in the form of microcrystalline components.

a



b

d

e

f

The crystals are always in close contact with other components of the rocks and have formed, therefore, without any recognizable pattern, thus forcing collectors to have great patience when searching.

c

Areas commonly searched are recently fractured rocks, either in quarries or on construction sites (also road cuts, tunnels, mines, and so forth) in order to find geodes or veins where the crystals had the chance of growing freely, thus having larger dimensions and well-developed crystalline patterns. Fortunately, feldspar crystals are not greatly coveted by the average construction worker or miner. Moreover, wherever the crystals tend to be large in size, the quarried material diminishes in value and is generally thrown away, making these minerals particularly easy to find in the dumps of quarries and mines.

Illustration 4a shows a specimen of orthoclase [$KAlO_2(SiO_2)_3$], which crystallizes in the monoclinic system. This specimen is exceptional, giving a very clear view of the growth of the accessory elements that are developed in a characteristic manner on one of the faces. Illustration 4b is another crystal of orthoclase, a fine example of twinning in accordance with Carlsbad's law.

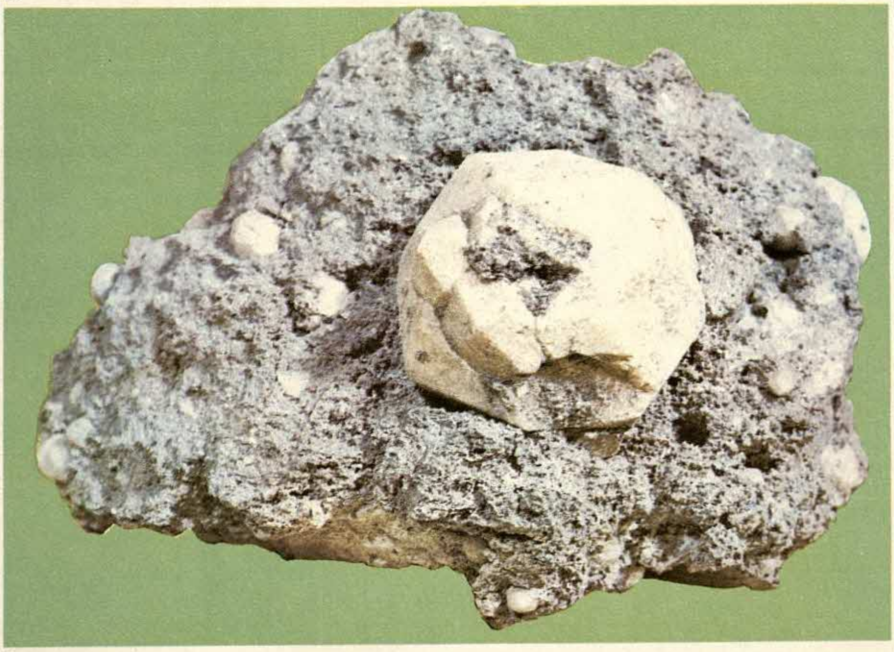
Illustration 4c shows a specimen of sanidine, a variety of orthoclase that also contains sodium, again twinned according to Carlsbad's law. An accessory element has grown on one of the faces, its axis orientated in the same direction as the axis of the principal crystal. Illustration 4d shows another geminate specimen of sanidine. As can be seen, the faces of all these specimen are not perfectly smooth; the crystals are impure and consequently opaque.

The family of feldspars also includes the sodium variety of plagioclase, which is known as albite, (Illustration 4e). A specimen like this should always be kept unbroken when detached from surrounding rocks. Only in cases where one of the larger elements attains truly exceptional dimensions and a perfect form (because it is not restrained by the presence of other crystals) would it be desirable to detach it from the specimen and isolate it completely, as has been done in the case of the crystals shown in the previous illustrations.

The calcium variety of plagioclase is known as anorthite (Illustration 4f). This specimen is particularly interesting because the pink crystals of anorthite are directly attached to the bedrock.

5

a



b

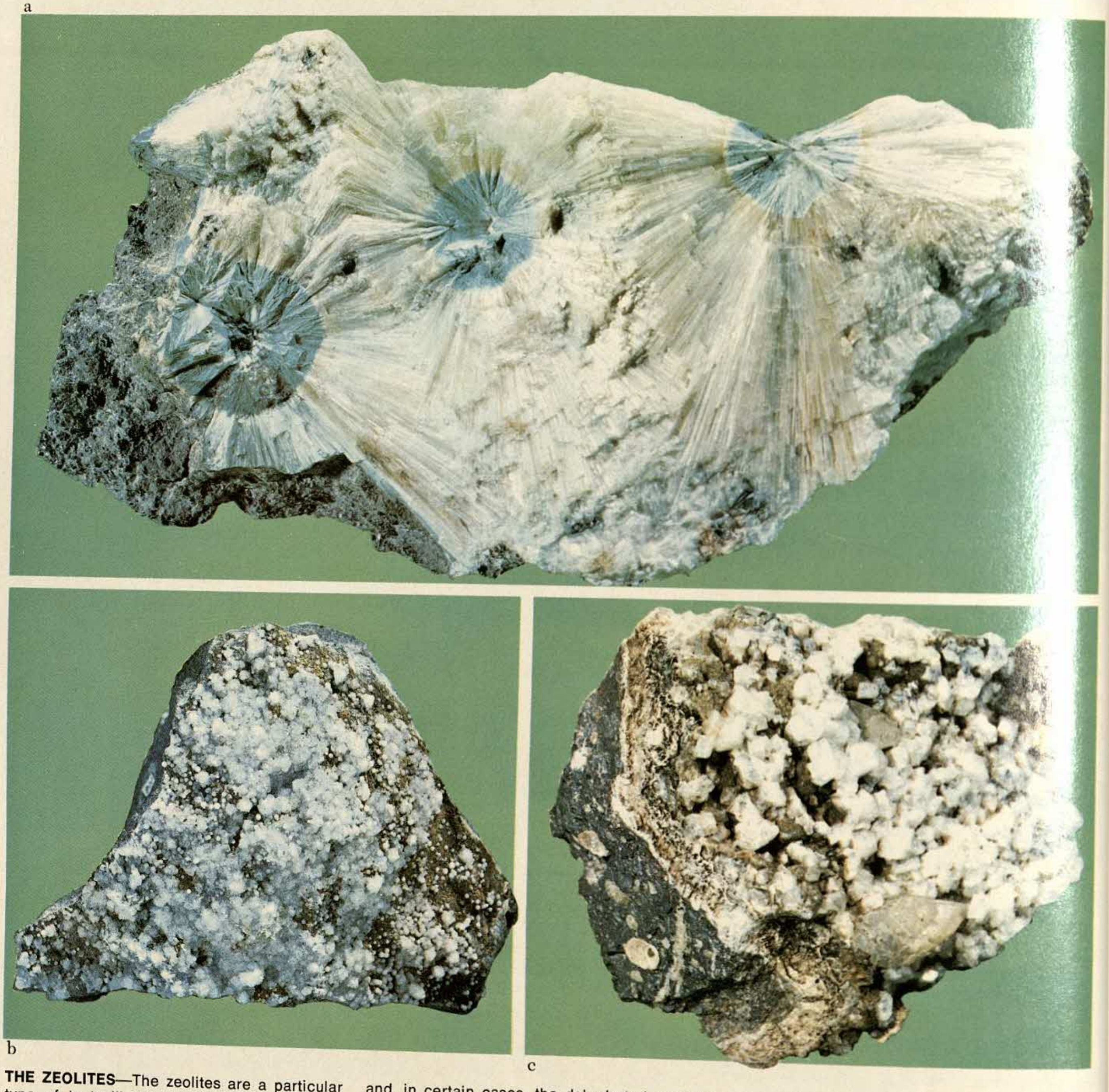
c

TECTOSILICATES WITHOUT EXTRANEOUS ANIONS—In classifying the tectosilicates, a first, broad subdivision is made of tectosilicates that do not contain any extraneous anions (these tectosilicates are illustrated); then, of tectosilicates that contain extraneous anions; and lastly, tectosilicates that also contain water molecules in their crystal lattices and are called zeolites. Each of these large groups is then subdivided into 13 various subgroups.

Illustration 5a shows a crystal of leucite, $KAlO_2(Si_2O_4)$; this particular specimen is from the slopes of Mount Vesuvius. These beautiful crystals are common among the ancient or recent lavas of Mount Vesuvius or among the volcanoes in Latium. All the same, a specimen such as that illustrated is rather rare, particularly because of the difficulty in detaching it from the bedrock without breaking it. Illustration 5b is a specimen of pollucite, a mineral far more rare than leucite, and corresponding to the chemical formula (Na,Cs) $(Al_2O_4Si_4O_8)$. At times, pollucite also contains lithium, rubidium, potassium, and thallium. Leucite, on the other hand, often contains potassium, occasionally rubidium, and, more rarely, sodium. The concern here is with minerals that contain considerable quantities of the heavy and rare alkaline metals.

Illustration 5c shows a specimen of petalite, $LiAlO_2Si_4O_8$; this is one of the principal minerals of lithium.

6



THE ZEOLITES—The zeolites are a particular type of tectosilicate in which the chains of the tetrahedrons of silicon and oxygen are arranged in a structure that leaves ample space for water molecules. These water molecules, however, do not form a stable part of the crystalline structure as they do in the hydrated salts; the water of the zeolites can be removed from the crystals by means of heating and, in certain cases, the dehydrated crystals will increase in volume. However, because their absorption tendencies are considerable, the dehydrated zeolites will readily reabsorb the water. It is also possible to introduce other molecules into the crystalline structure—for example, ammonia.

Illustration 6a shows a specimen of natrolite, $Na_2(Al_2Si_3O_{10})2H_2O$, while Illustration 6b shows a specimen of phillipsite, $KCa(Al_3Si_5O_{16}) \cdot 6H_2O$. Illustration 6c shows a specimen of chabazite, which corresponds to the chemical formula $(Ca,Na_2)(Al_2Si_4O_{12}) \cdot 6H_2O$.

All these photographs show quite exceptional specimens that collectors are likely to find and recognize only after long experience.

THE SILICATE FAMILY | nesosilicates, sorosilicates, and cyclosilicates

Of all the minerals known to man, the silicates are probably the most significant. They compose 87 percent of the mass of the Earth's crust. Silicates constitute almost all of the volcanic rock minerals and a large percentage of sedimentary rock. Silicates are usually found as microcrystals and, as such, constitute extensive masses of rock. The study of the complex silicates is a major task of crystallography.

The overwhelming abundance of silicates in rocks makes them the subject of study by petrologists and geologists. One technique employed in studying silicates is to slice the rocks into sheets about 0.0025 mm (about 0.00009 in.) in thickness. These thin sections are placed between thin glass and observed microscopically under polarized light. This procedure is complicated, however, because of the great number of crystalline types that must be considered.

Another method used to study silicates is liquid chemical analysis. This is complicated by the fact that most silicate compounds are highly resistive to acids. One effective way to study silicates in this manner is by dissolving them in hot hydrofluoric acid. Here, too, the analysis is difficult because of the many elements within the silicates. Some elements are found only in traces; but the fact that they are there, even minutely, makes the analysis all the more difficult.

Other methods used by mineralogists and geologists are little more effective. Analysis by x-ray fluorescence, for example, does not provide optimum results, again because of the wide variety of elements present in the silicates and because some impurity invariably complicates the analysis.

In spite of all these difficulties in analysis, the search for silicates is a rewarding one. Many of the minerals, as the illustrations show, are quite beautiful.

SOME INDUSTRIAL USES

The silicates are the foundation material for the ceramic industries. In the United States, these include not only industries based upon clay but also those that use earthy raw materials such as sand, feldspar, or magnesite in manufacturing products with the aid of a kiln or furnace. Ceramic industries in the United States include glass, vitreous enamels, portland cement, and certain abrasives as well as structural clay products such as building brick, paving brick, tile, and refractories. Other ceramic products are earthenware, china, stoneware, decorative porcelain, and electrical insulator porcelain.

THE FAMILY OF SILICATES — Silicates are classified by the relationship of their structures. Scientists consider, first of all, the ratio of oxygen and silicon atoms present in the crystal; second, there is the form in which the atoms of the two elements are assembled within the crystal. Nesosilicates, for example, are those in which silicon and oxygen appear independently under the form of tetrahedral combinations SiO_4. The name nesosilicate begins with a form of a Greek word meaning "island." Hence, "nesosilicate" means an "island crystal of independent silicon."

The names of the other silicate types have similar etymologies. "Soro" comes from the Greek for "heap," and "cyclo" means "wheel" or "circle." These prefixes are used in an attempt to picture the structures of these silicates. The other types are formed, in most cases, by the solidification of magma. Some types occur through ion exchange or by precipitation from solutions.

The silicates are only very slightly soluble, but this slight amount of solubility aids, over a very long period of time, in the formation of a perfect crystalline structure.

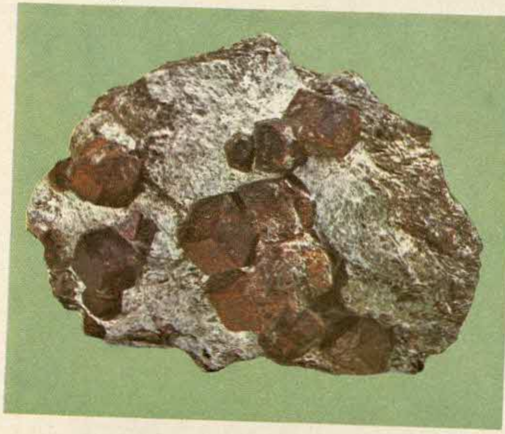
1

Si:O	ANION COMPLEX	MINERAL EXAMPLE	SUBCLASS
1:4	(SiO_4) isolated tetrahedron	fosterite $Mg_2(SiO_4)$	nesosilicate
2:7	(Si_2O_7) double tetrahedron	thorveitite $Sc_2(Si_2O_7)$	sorosilicate
1:3	(Si_3O_9) triangular ring	benitoite $BaTi(Si_3O_9)$	cyclosilicate
1:3	(Si_4O_{12}) quadrangular ring	neptunite $Na_2FeTi(Si_4O_{12})$	cyclosilicate
1:3	(Si_6O_{18}) hexagonal ring	beryl $Al_2Be_3(Si_6O_{18})$	cyclosilicate
2:5	$(Si_{12}O_{30})$ hexagonal ring	milarite $KCa_2AlBe(Si_{12}O_{30})$	cyclosilicate
1:3	(Si_2O_6) simple chain	diopside $CaMg(Si_2O_6)$	inosilicate
4:11	(Si_4O_{11}) double chain	tremolite $Ca_2Mg_5Si_8O_{22}(OH)_2$	inosilicate
2:5	(Si_4O_{10}) sheet	talc $Mg_3(OH_2)\ Si_4O_{10}$	phyllosilicate
3:8	(Si_3AlO_8) framework	albite $Na(Si_3AlO_8)$	tectosilicate

GARNETS—The garnet, a relatively common mineral, is a nesosilicate with the formula $Me_1{}^{+2}ME_2{}^{+3}(SiO_4)_3$, where Me_1 and Me_2 are different metal ions; it contains three isolated tetrahedra of SiO_4. Garnet crystals have a monometric structure.

The types of garnet shown contain bivalent iron and aluminum. This type, called almandite, is not the only type of garnet. When combined with manganese and aluminum, the garnet is called spessartite; when combined with magnesium and aluminum the type is called pyrope. All these are in the almandite series. Another series of combinations, called anfradites, contain aluminum and calcium (grossularite), calcium and iron (andradite), and calcium and chromium (uvarovite).

2a



2b

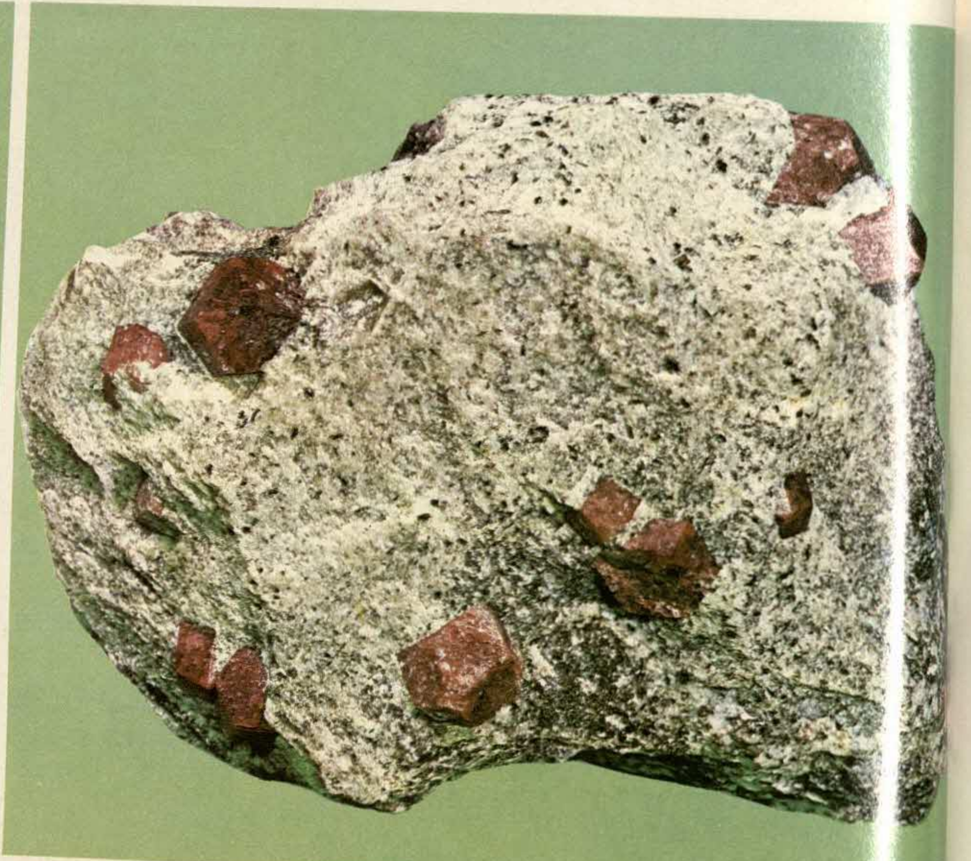


Illustration 2a shows the rhombic dodecahedron crystals characteristic of garnets. These red crystals are quite fractured and are not perfectly transparent.

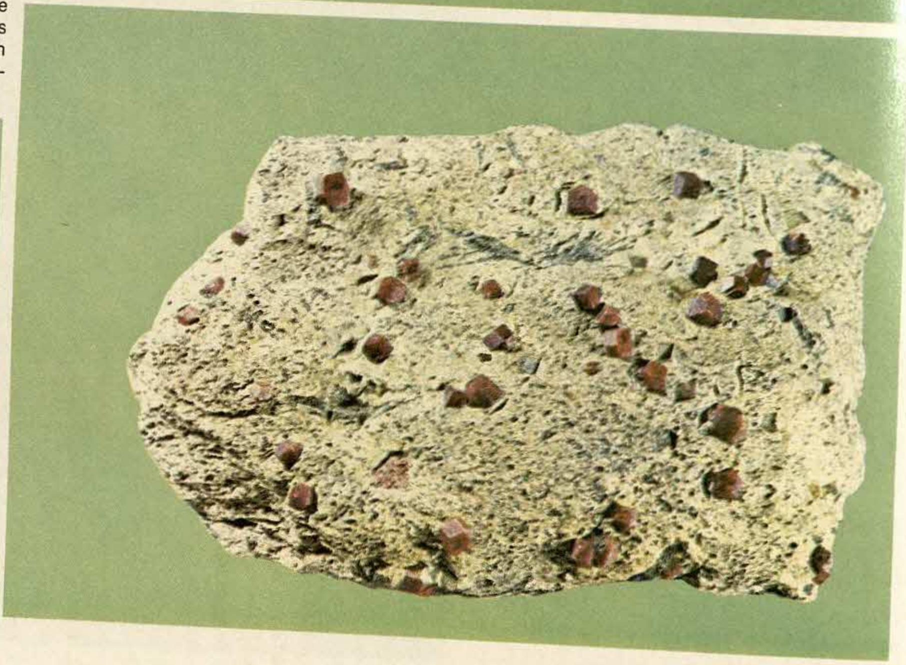
Illustration 2b is another example of the almandite series. This specimen is slightly clearer and has a pinkish tint.

Illustration 2c shows garnet crystals in the form of cubes. Such a specimen is rare. This specimen is also quite clear and transparent.

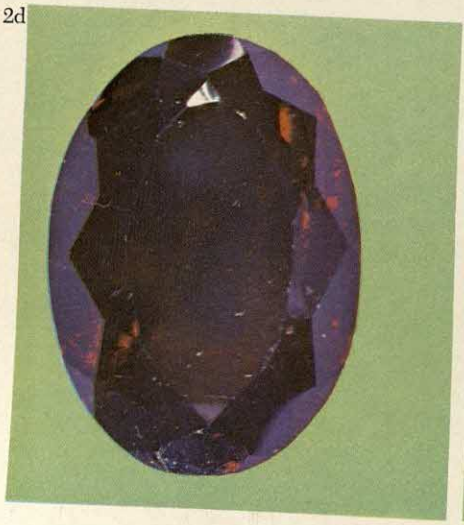
Illustration 2d shows a large transparent crystal that has been cut into a gem.

Garnets are found throughout the world in volcanic rocks. The type of garnet found usually corresponds closely to similar elements found in the mother rock. Pegmatite, for example, often contains the element manganese. If manganese is present in the rock, it is quite probable that spessartite, which contains manganese, will also be present. Some of the places in the United States where garnet is found are Pilar, New Mexico; Marshall, North Carolina; Amelia, Virginia; and Holland, Oregon.

2c

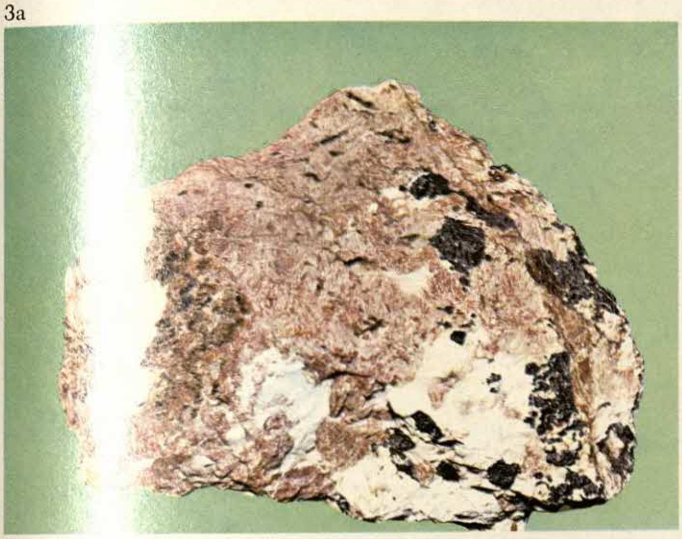


2d

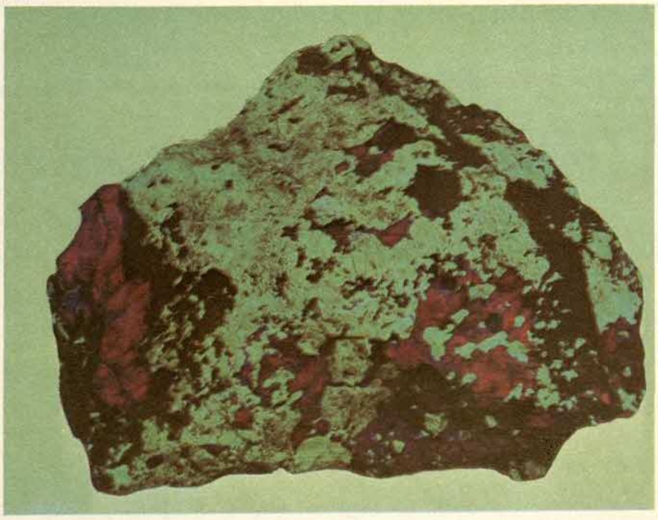


WILLEMITE—This is a nesosilicate with a very simple formula—Zn_2SiO_4. Reddish-brown in color, it is shown with calcite in Illustration 3a. The mineral is easily distinguished by its green coloring under ultraviolet light (Illustration 3b).

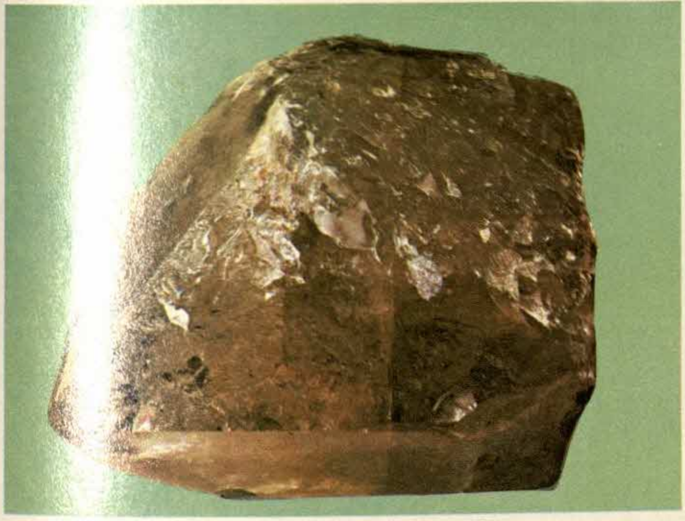
3a



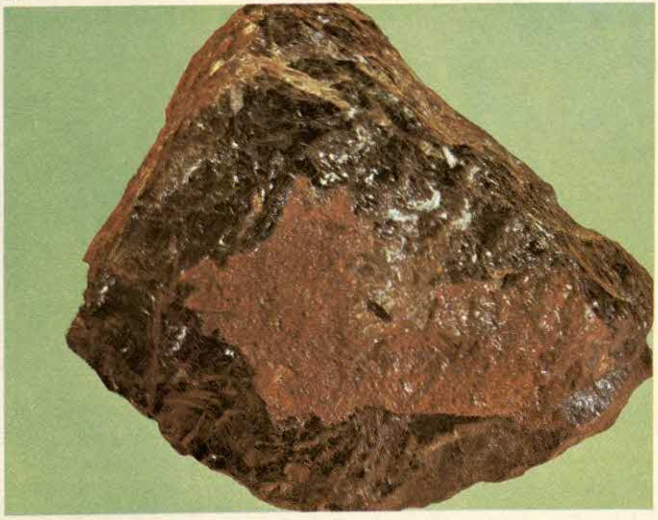
3b



4a



4c



THE SUBNESOSILICATES — The subnesosilicates differ from the nesosilicates in that they contain other anions in addition to SiO_4. The most celebrated subnesosilicate is the topaz, known for its beauty and its large crystals.

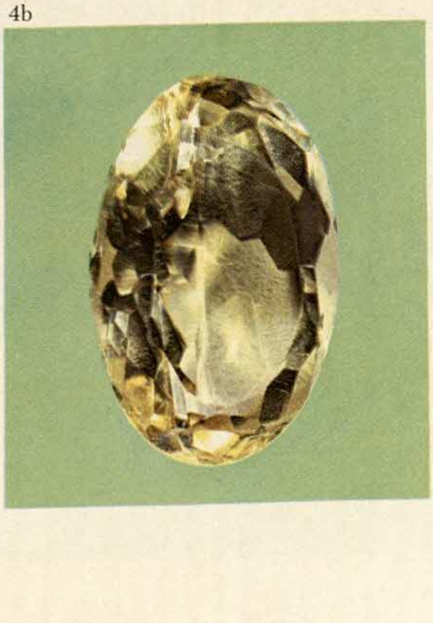
Illustration 4a is a large topaz. The large crystals in this specimen, like those in other large topazes, have a weak coloration, which renders it unsuitable as a gem. The value increases as the color becomes more intense. Some topazes weigh up to a quarter of a ton.

Topazes are found in the quartz-bearing porphyry of the Thomas Mountains in Utah and in Conway, New Hampshire. The topaz formula is $Al_2(F_2SiO_4)$.

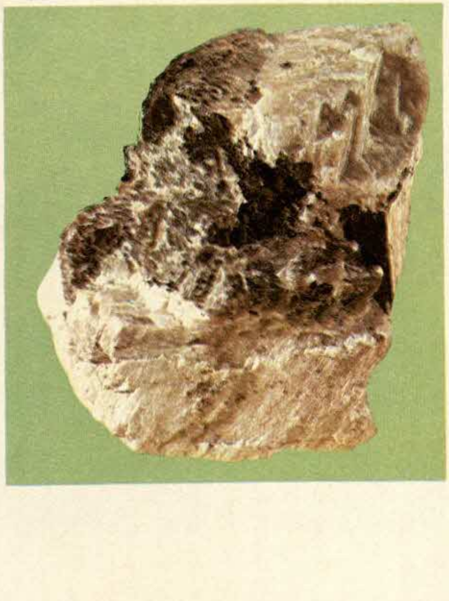
Illustration 4b shows a pale yellow topaz cut as a gem.

Illustrations 4c and 4d are examples of relatively rare subnesosilicates found almost exclusively in Norway. Illustration 4c is a sample of wohlerite, while Illustration 4d is gadolinite, which contains some rare earths.

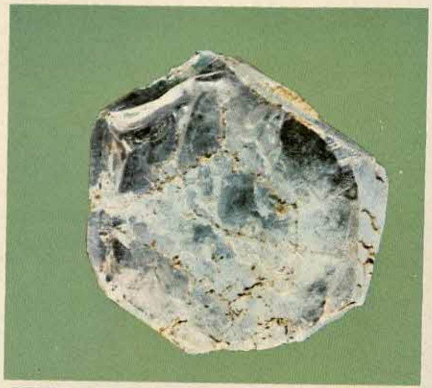
4b



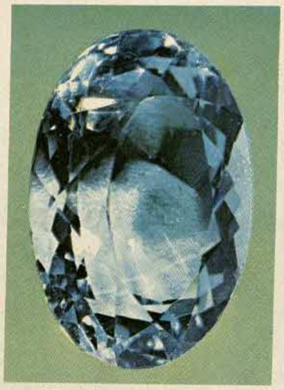
4d



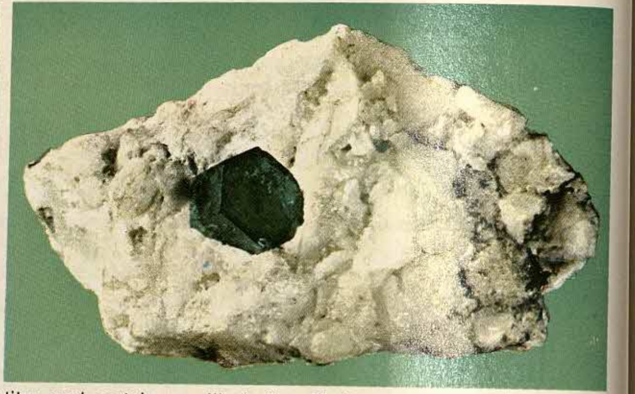
5a



5b



5c



BERYLS AND EMERALDS — These minerals are examples of sorosilicates, a name derived from the Greek meaning "heap" or "group." The chemical formula is based on Si_2O_7.

The most outstanding of the sorosilicates is beryl. Chemically the same as an emerald, beryl is compounded with aluminum and beryllium—$Al_2Be_3(Si_6O_{18})$.

Beryl is found with pegmatites and certain metamorphic rocks such as gneiss and mica schist. In the United States, beryl is found in North Carolina. The most beautiful and valuable beryls come from Brazil.

Illustration 5a is a beryl specimen that is partially transparent. Beryl is evaluated by its transparency, color, and tonality.

Illustration 5b is a gem-cut blue beryl.

Illustration 5c shows an emerald in its natural state. An emerald is actually a pure beryl of an intense green color. The largest source of emeralds is Colombia, South America. Emeralds are highly prized, and a perfect one is more valuable than many diamonds of equal weight.

THE TOURMALINE — Tourmalines are cyclosilicates with extremely complex formulas. There are many varieties, depending on the ions linked to the silicon. Tourmaline is found almost exclusively in large prismatic crystals, usually opaque black. Some varieties are transparent and much more valuable. The transparent forms are used for optics and ornamentation, especially the red or green varieties.

In the United States, tourmaline is found in Maine, but the principal source is the European Alps, where the mineral is found in the alluvium or the debris of moraines, in the upper stream beds.

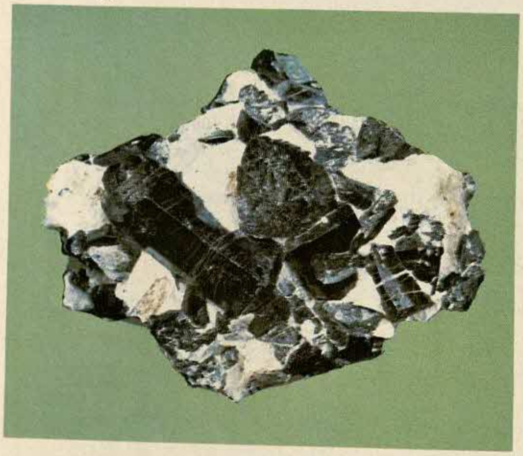
Illustration 6a shows tourmaline crystals associated with feldspar of a pegmatite. It is not unusual to find feldspar, tourmaline, beryl, quartz, and mica in the same specimen.

Illustration 6b shows large, striated, pyramidal crystals of tourmaline.

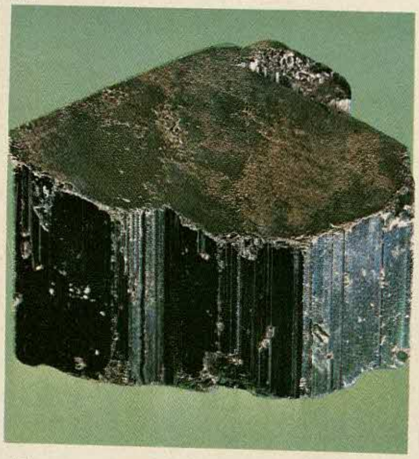
Illustration 6c is one of the transparent varieties of tourmaline, with a red coloring intense enough to make a precious cut gem.

Illustration 6d is an unusual formation in that the tourmaline crystals are rod-shaped.

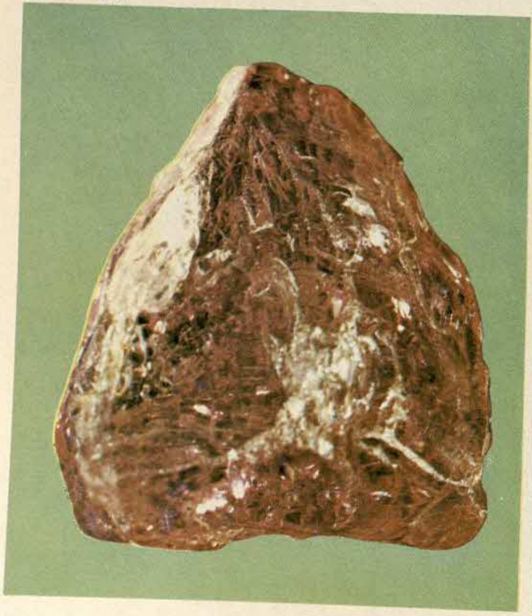
6a



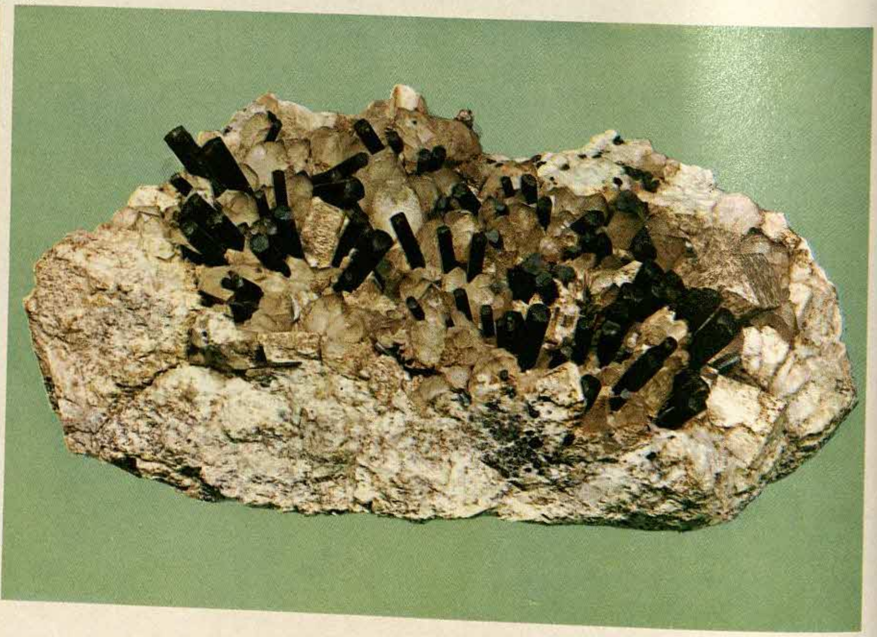
6b



6c

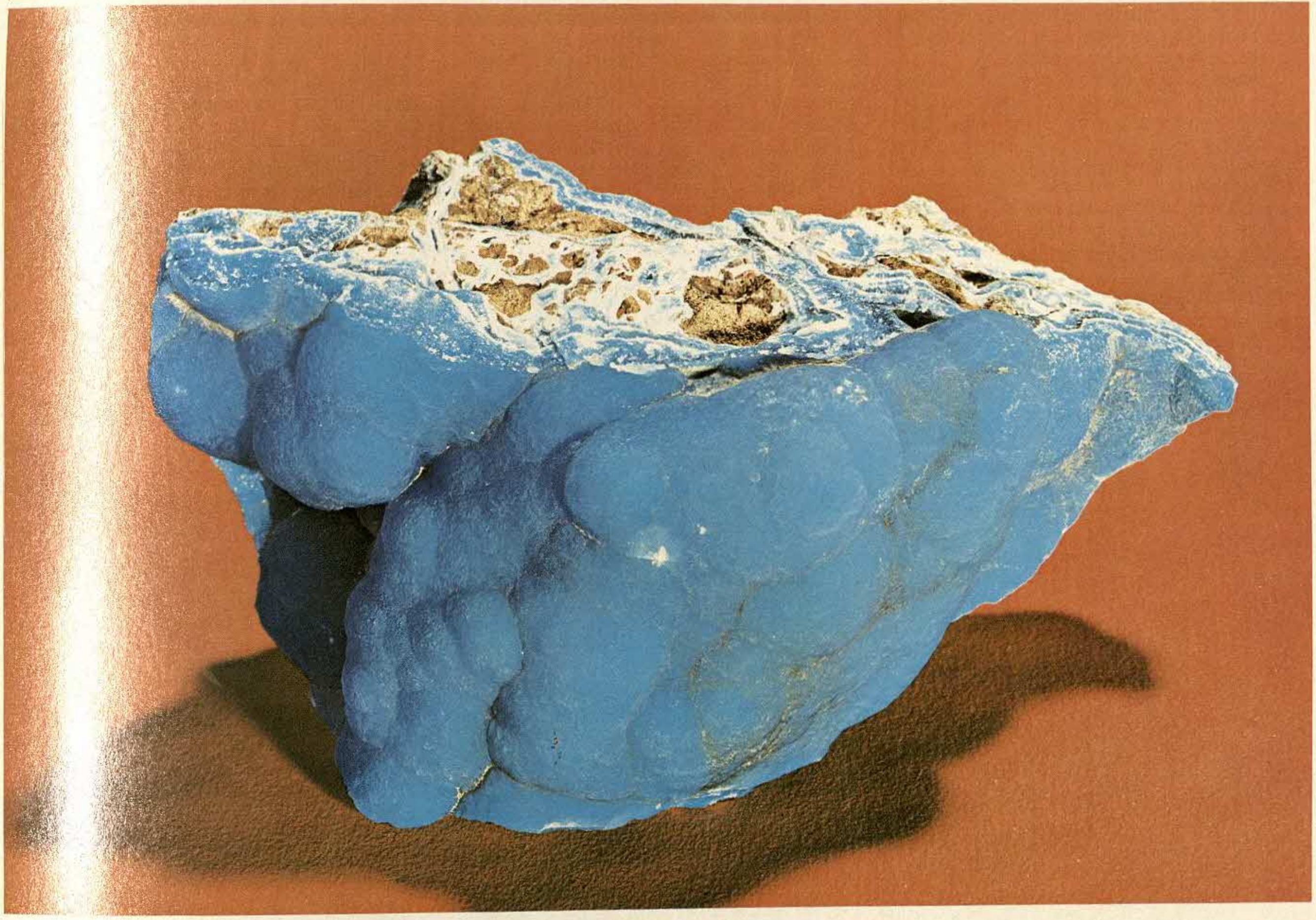


6d

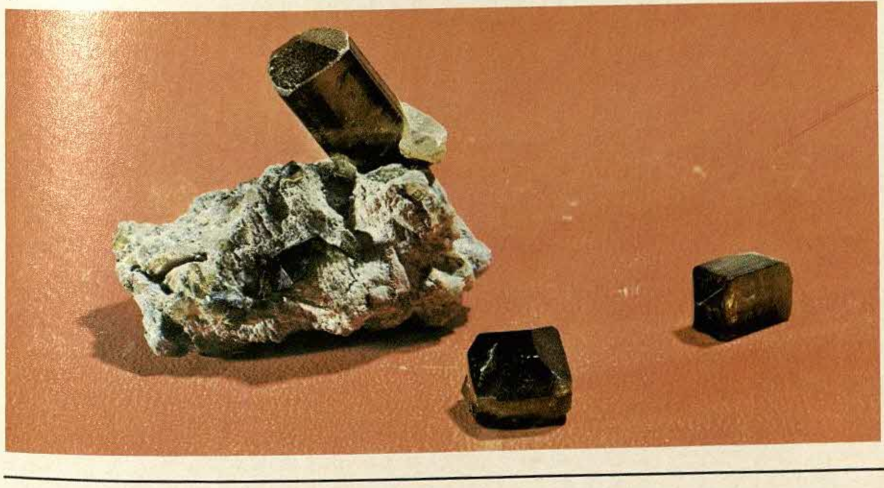


CALAMINE—One of the few silicates with a relatively simple formula is calamine, a hydrous zinc silicate. It has the chemical formula $Zn_4[(OH)_2SiO_7]\cdot H_2O$. It crystallizes in the rhombic system and is formed in contact with zinc deposits. The reaction of zinc in veins of rock forms the calamine. Samples are found in New Mexico and are prized for their characteristic blue coloration.

7



8



A VERY COMPLICATED SOROSILICATE—The formula for vesuvianite or idocrase, which, like calamine, belongs to the sorosilicate class, is a very complex one: $Ca_{10}(Mg, Fe)_2Al_4[(OH)_4(SiO_4)_5(Si_2O_7)_2]$. The coloring ranges from yellow to brown, depending on the presence of iron. This material is found through much of the world, often beautifully crystallized with a ditrigonal bipyramidal structure.

As the name suggests, vesuvianite is found in volcanic rocks.

SULFATES AND PHOSPHATES

in rocks of metamorphic and organic origin

1

A LARGE VARIETY OF GYPSUMS—The chemical formula of gypsum is $CaSO_4 \cdot 2H_2O$; the mineral always originates from a deposition of the salt from saturated solutions.

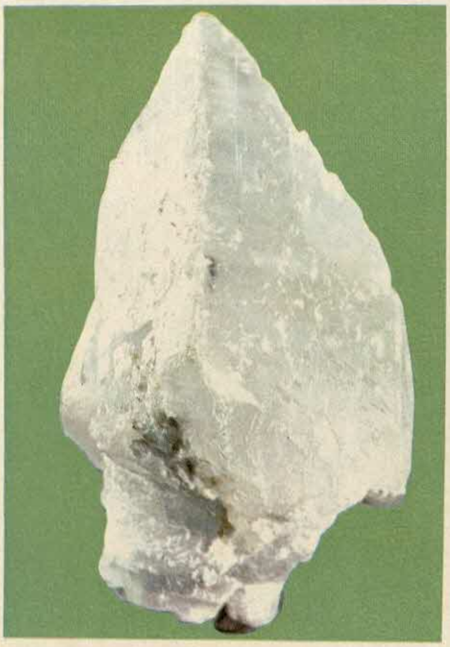
Gypsum crystals such as that in Illustration 1a are fairly common. Such crystals are not perfectly pure because the mineral has been polluted by other compounds present during its crystallization. However, very beautiful and pure crystals can be found in Italy, especially in Emilia, and in the gypsum caves of Tuscany.

Gypsum crystals are often found joined along their major axes, forming twin crystals that (because of their characteristic form) are often called lance-headed crystals (Illustration 1b). Polycrystalline specimens are found in stalactites formed by microcrystals twinned according to this process. The specimen shown is very pure; its opacity is due to the presence of numerous fractures along the characteristic cleavage planes.

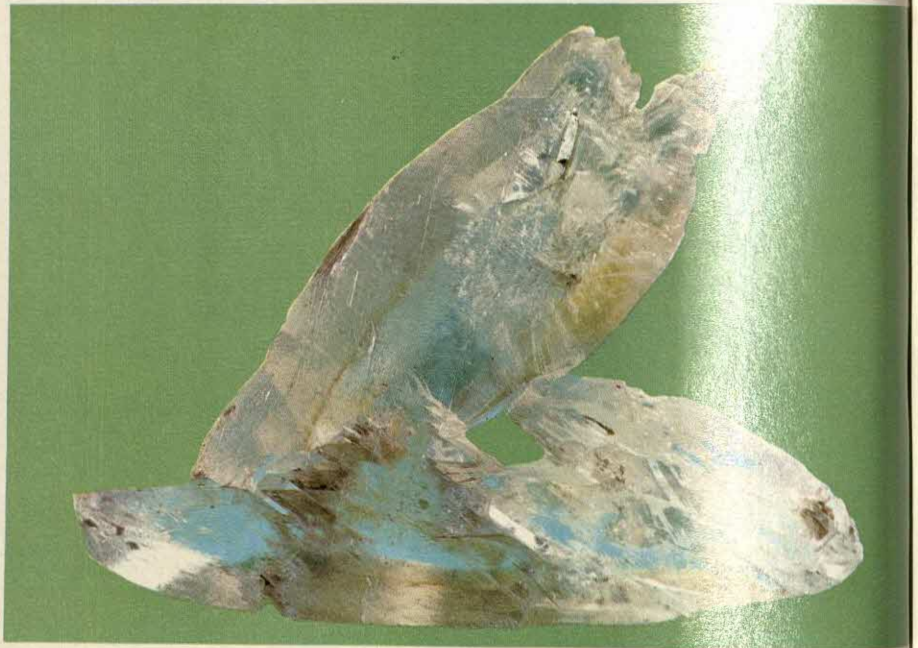
The crystal in Illustration 1c is called the desert-rose. It is found in extremely arid climates—commonly in deserts, and is formed by dissolved gypsum that is carried to the ground surface by the capillary action of water, which deposits the gypsum on the surface in crystals that arrange themselves in petallike formations. The pink color is a result of pollution by a fine red dust derived from desert sands. This crystal is easily found in shops catering to collectors.

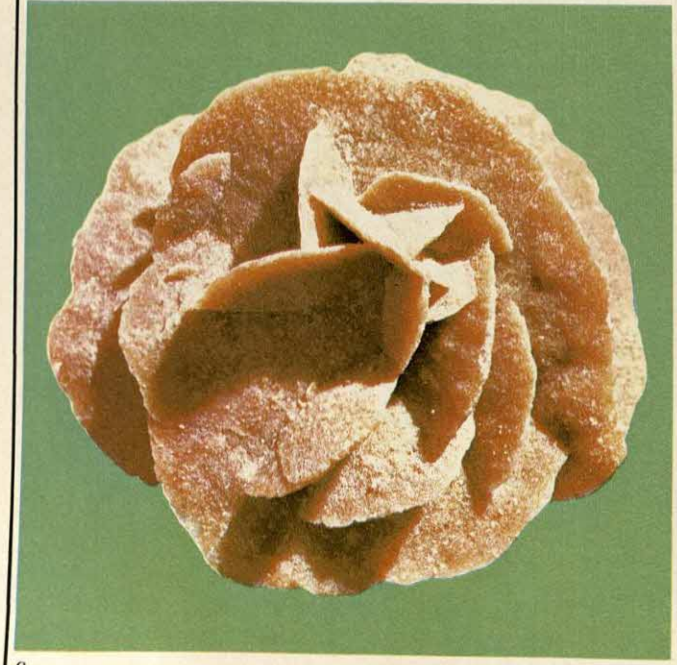
Illustration 1d is a coralloid crystal, so-called because of its branchlike formation of crystalline fibers that are arranged in parallel, bent bundles. This specimen is from Italy, and is a rarity. However, gypsum is quite common to Italy, where it forms large rock masses from which alabaster is extracted.

a



b





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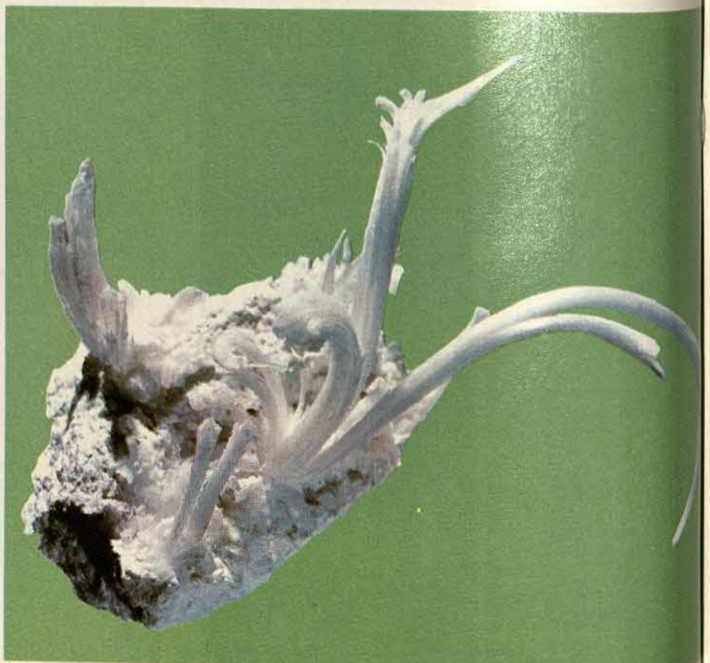


d

Among the various reasons people collect minerals, one of the most important is to obtain samples from which mineral formation can be better understood. For example, an observation of the form, dimension, color, and other characteristics of samples shows that crystalline forms of the same chemical species differ from one another. These differences are a result of different formation temperatures, or different ways in which the basic minerals were deposited—from liquids, fused materials, or vapors, by ion exchange, or by recrystallization. Such studies are usually conducted by specialists, but the nonspecialist may also engage in them if he has the samples and equipment with which to work. The most interesting investigations are those carried out on the specimen itself, although this often results in destruction of the specimen. For this reason, collectors often acquire more than one specimen of a mineral, thus permitting preservation of the more beautiful—or valuable—specimens, while others are used for analysis.

This article deals primarily with the sulfate family of minerals. Sulfates are both interesting and relatively easy to find (gypsum is the most common). Phosphates are also discussed, although these are more rare—such as the interesting uranium phosphates.

SULFATES

Gypsum is a sulfate composed of calcium crystallized with two water molecules. It originates from salt, which has a fairly high solubility in water, even greater than that of calcium carbonate. Gypsum and calcite are often found associated in sedimentary areas, although gypsum is less abundant than calcite in these areas. Gypsum usually is found wherever sulfur occurs. Large and highly pure crystals have been found in Sicily and Italy. Although they present obstacles to obtaining specimens, caves are a rich source of gypsum, especially where it has been deposited from waters with regular flow and composition. It is sometimes possible to find cave crystals of great purity having dimensions of up to half a meter. Gypsum also forms extensive masses of rock from which alabaster is extracted.

Gypsum forms the cement of some sandstones. In such cases, a sediment of loose sands has been crossed by waters containing dissolved calcium sulfate; the precipitation of the mineral in the interstices of the sand mass has led to the cementation. Sandstones and alabasters, however, are not hard and resistant rocks; when exposed to the action of rainwater, they tend to dissolve.

Gypsum is sometimes found together with its anhydride, pure calcium sulfate without the crystallization water. This mineral is of metamorphic origin, generally from a gypsum deposit from which the water has been removed by means of some thermal action. The anhydride form is much rarer than ordinary gypsum.

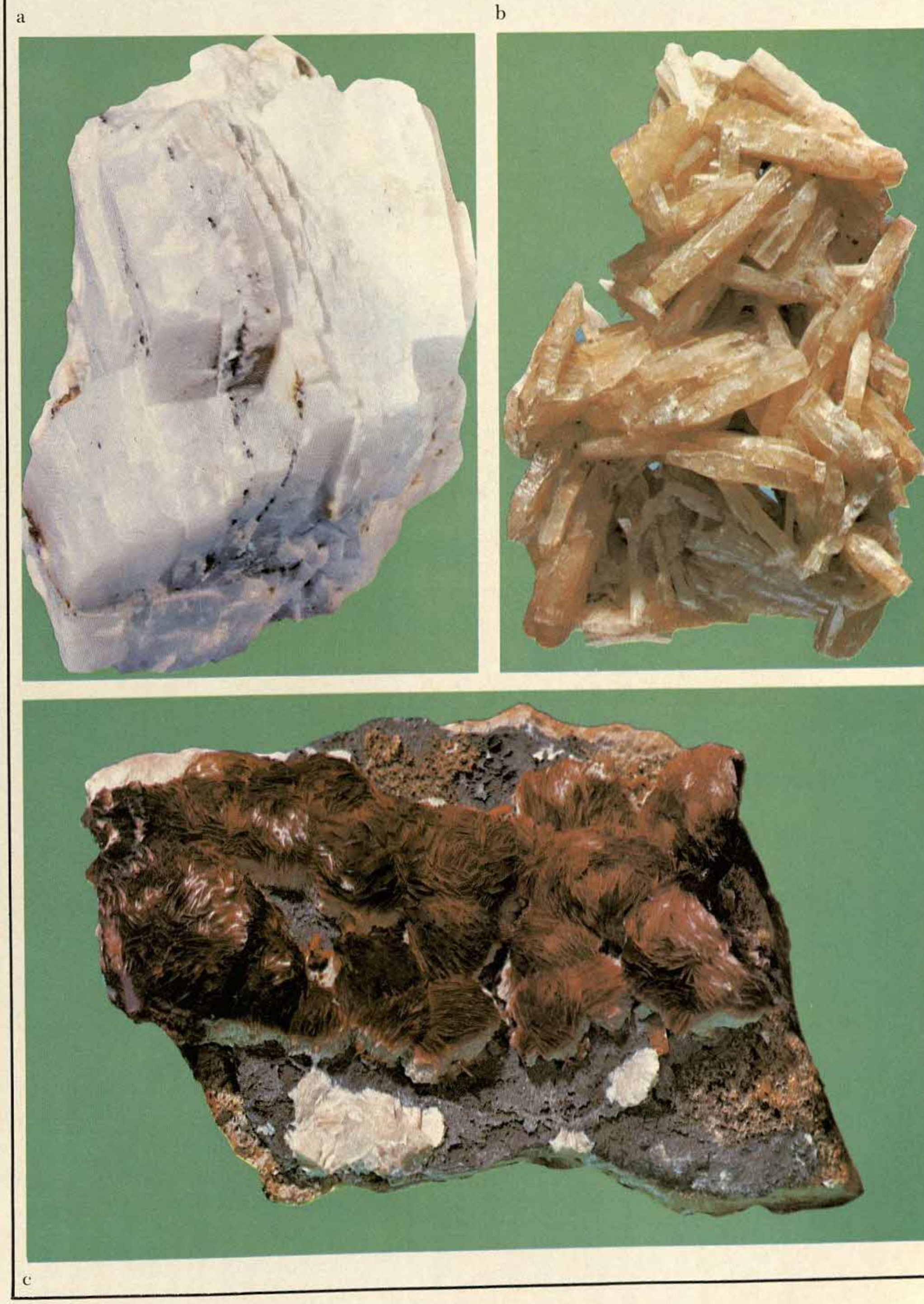
2

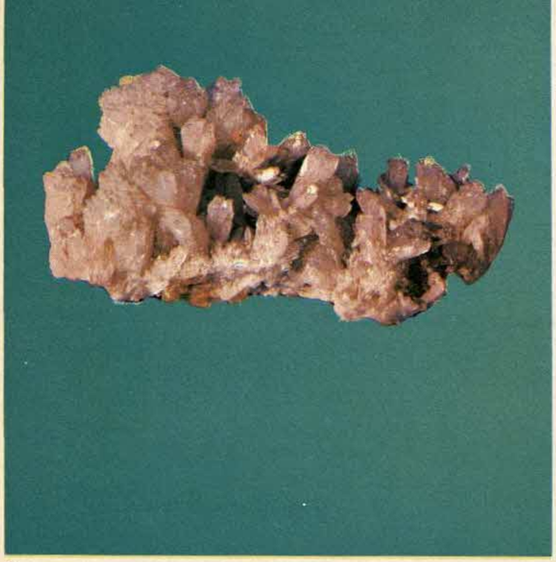
BARITE—Also known as heavy spar, barite is relatively difficult to find in its pure and translucent state because it is normally found mixed with other sulfates that render it opaque, or give it some characteristic coloration. In a pure state, however, its crystals are limpid.

Illustration 2a is a crystalline form of barite. This form is rhombic-bipyramidal and its crystals should, therefore, have a rather complex formation. Nevertheless, barite cleaves quite easily, so much so that on superficial examination it can be easily confused with calcite. Generally, however, barite is easily identified by its weight.

Illustration 2b is a barite druse. This photograph highlights crystal formation, and this particular specimen appears polluted. These colorations show the way in which the crystals were formed and indicate the polluting substances in the immediate area.

Illustration 2c is an exceptional barite specimen. Specimens such as these are found extensively in rock veins around Cortabbio, in Northern Italy.





3

CELESTITE, A RARE SULFATE—A sulfate of strontium and a relatively rare mineral, celestite is generally associated with gypsum and aragonite in gypsum and sulphur deposits. Celestite has the same crystalline structure and cleavage as barite.

BARITE

The name of this mineral, which is made up of barium sulfate, is derived from the Greek work meaning "heavy." Fifty-nine percent of the mineral is accounted for by barium, an element that has a high atomic weight and a specific weight of 4.5. Since the mineral is abundant and easy to extract, it is often used in place of kaolin or gypsum as a filler to increase the weight of various commercial products. Because of its high specific weight, barite is also used to produce heavy "muds" to prevent the escape of gas from oil wells that have caught on fire.

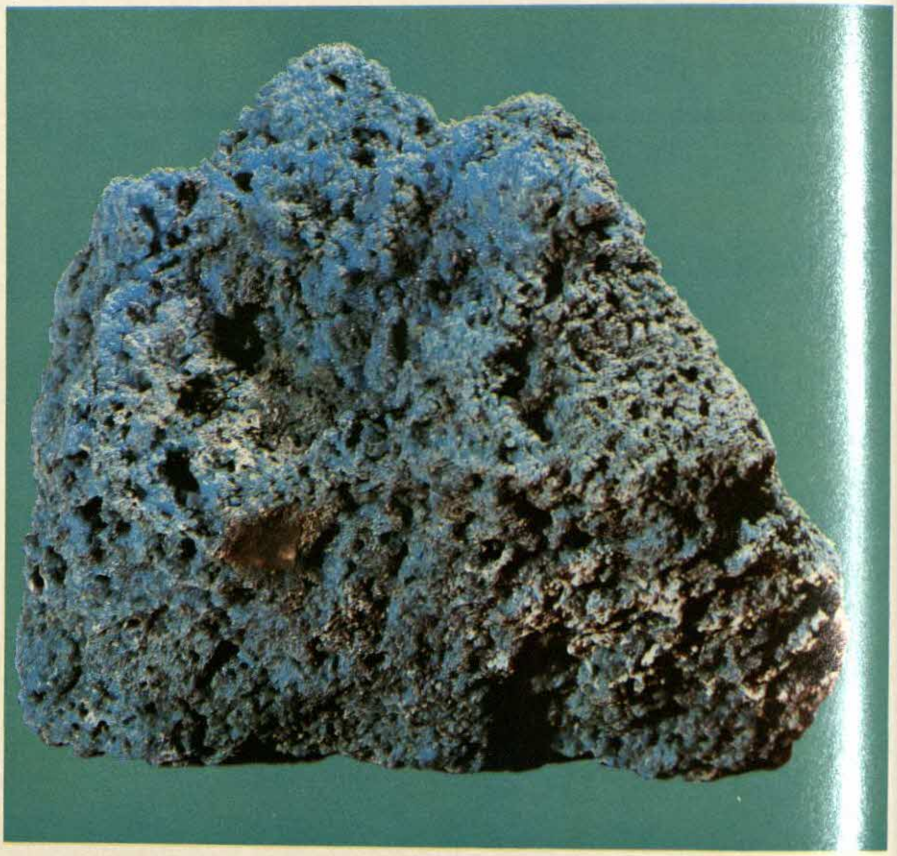
The origin of barite is usually hydrothermal (that is, formed by means of deposition from extremely hot waters) when it is found in metalliferous veins; elsewhere, it is usually formed by deposition from waters in which it is dissolved. Like gypsum, barite often forms the cement of sandstone masses. Barite localities are widespread in both Europe and North America. In the United States, the mineral can be found in New York, Connecticut, and Pennsylvania; Virginia, Georgia, and Tennessee; Michigan, Missouri, and South Dakota; as well as in Colorado, Utah, Oklahoma, and New Mexico. Barite deposits can also be found in Ontario and Nova Scotia in Canada.

PHOSPHATES

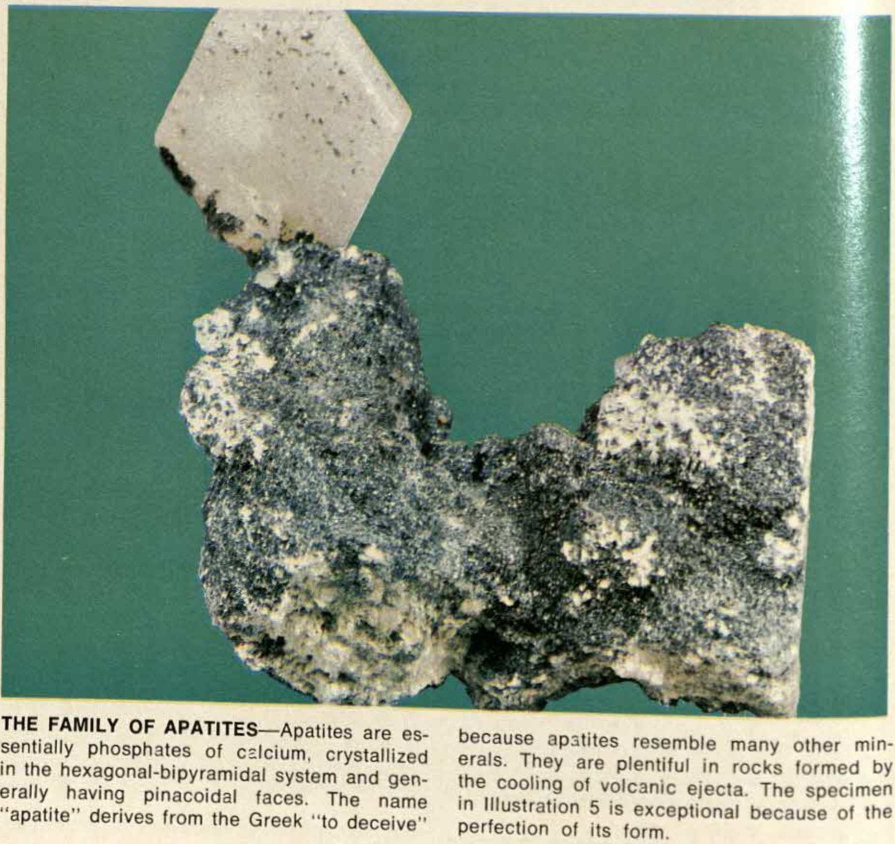
Turquoise $[CuAl_6(OH)_8(PO_4)_4 \cdot 4H_2O]$ is a phosphate used as jewelry and is known in two varieties, oriental and occidental. The former is of hydrothermal origin and is found in the clefts of weathered trachytes in Central Asia; occidental

CHALCANTHITE—An extremely soluble mineral, chalcanthite is natural copper sulfate, which is found crystallized with five water molecules. Because of its soluble nature, it is difficult to find, generally existing only in particularly arid climates or in highly localized deposits. Copper sulfate is usually formed as a weathering product of copper minerals. It is common in Chile and is one of the principal sources of that country's copper. The specimen illustrated is from Chile.

4



5

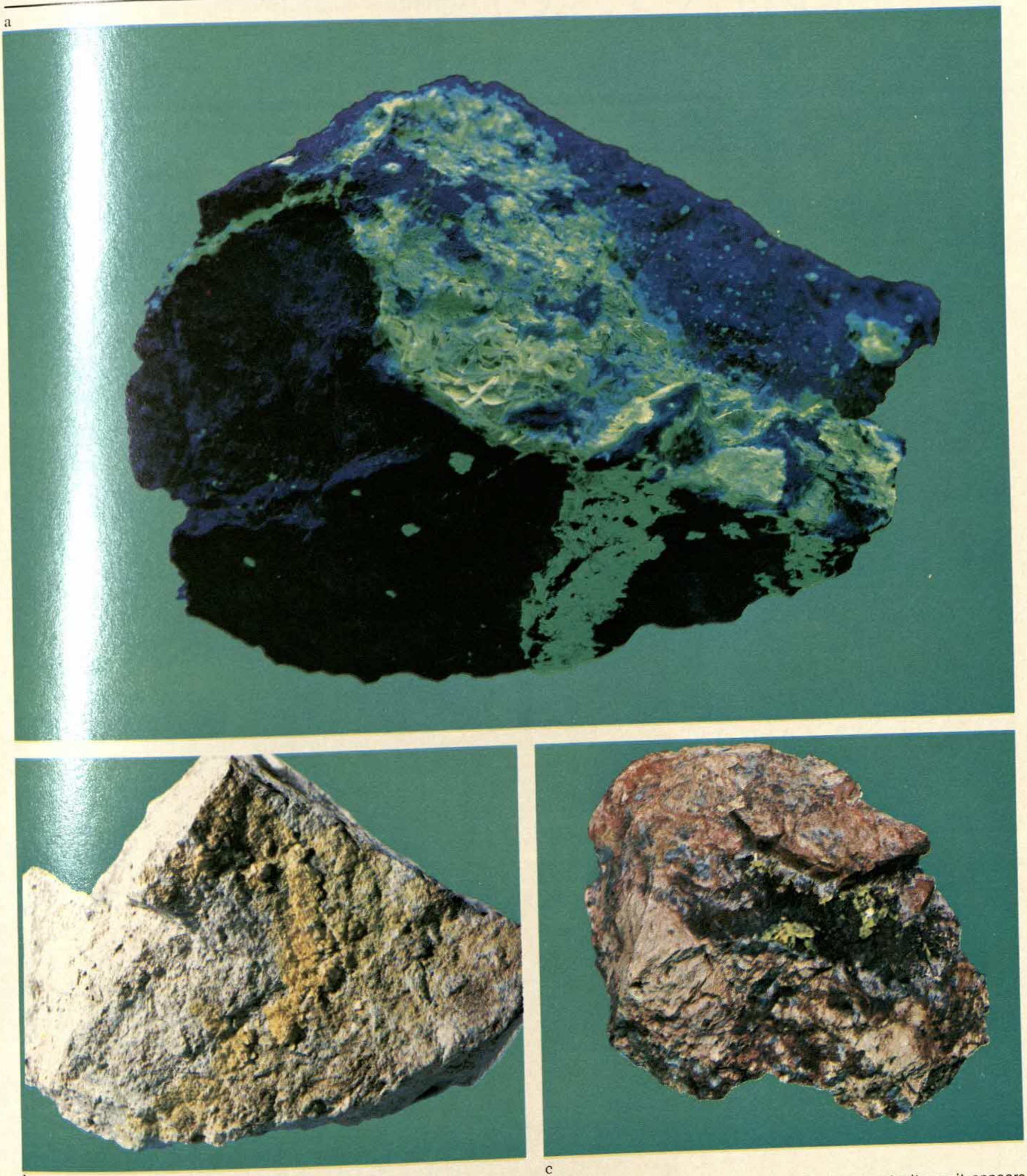


THE FAMILY OF APATITES—Apatites are essentially phosphates of calcium, crystallized in the hexagonal-bipyramidal system and generally having pinacoidal faces. The name "apatite" derives from the Greek "to deceive" because apatites resemble many other minerals. They are plentiful in rocks formed by the cooling of volcanic ejecta. The specimen in Illustration 5 is exceptional because of the perfection of its form.

turquoise, a less precious stone, derives from an infiltration of copper salts and the consequent ion exchange in the fossils of Tertiary deposits. This variety of turquoise is commonly found in Mexico and the southern United States.

Monazites, phosphates of the rare earths, are useful to industry and are also interesting to the collector.

6



THE PHOSPHATES OF URANIUM — Uranium minerals are numerous, and many of them are phosphates. Nevertheless, the mineral used almost exclusively for the extraction of uranium is uranium oxide, or pitchblende. Other phosphates containing uranium are of interest because they represent indices of uranium's presence in primary deposits from which the phosphates have spread out as a result of having been dissolved and carried away by water. Their study, therefore, is of great importance to uranium prospecting.

One of these phosphates (Illustration 6a) is autunite ($Ca(UO_2PO_4)_2 \cdot 10H_2O$). The photograph shows the most salient characteristic of autunite—its greenish-yellow fluorescence under ultraviolet light, which often reveals the foliations in which the autunite is crystallized.

Illustration 6b shows autunite as it appears in natural light.

Uranocircite (Illustration 6c) is a uranium mineral with a complex chemical formula [$Ba(UO_2PO_4)_2 \cdot 8H_2O$]. The formula is analogous to that of autunite. Uranocircite is far more difficult to find than autunite; the crystals are always found as thin crustations of small dimensions.

A COLLECTION OF CARBONATES

significant minerals for the collector

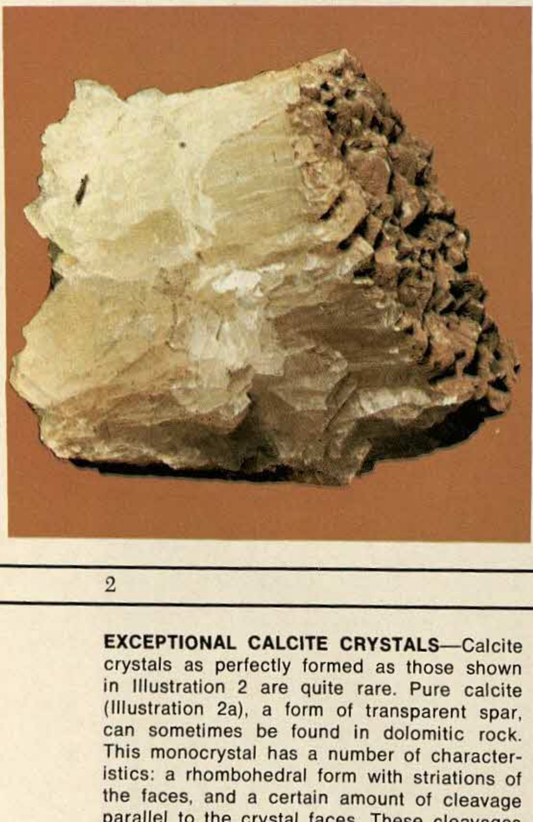
Carbonate minerals are compounds of oxygen, carbon, and one or more elements. The most common of the carbonate minerals is calcite, the mineralogist's name for calcium carbonate. Calcite is widely distributed in all sedimentary rock, and occurs in a variety of forms. Hence, calcite specimens are quite easy to locate; for this reason, the collector should be on the lookout for those crystals having a high degree of purity or an interesting color, or crystals that are associated with other minerals in unusual ways. While calcite is readily found, a second form of calcium carbonate, aragonite, occurs to a lesser extent. This crystalline form, therefore, can form the basis for rewarding fieldwork.

Innumerable other carbonate minerals occur in almost all sedimentary deposits. Some, like those of iron, are not only interesting to the mineralogist, but are industrially important as raw materials for the extraction of the primary metal. Others are used as gems, notably carbonates of copper and manganese. These are known, respectively, as malachite and rhodochrosite.

Perhaps the most conspicuous copper carbonate, bright green malachite is a useful guide in prospecting. The mineral is found in nearly all copper-mining districts. It is commonly associated with the deep blue azurite. Basic copper carbonates are formed when an alkaline carbonate is added to the solution of a copper salt. They are used in the preparation of pigments as well as for ornamental objects. Azurite is also known as chessylite, from Chessy, France, where many fine crystals belonging to the monoclinic system have been found.

1

a



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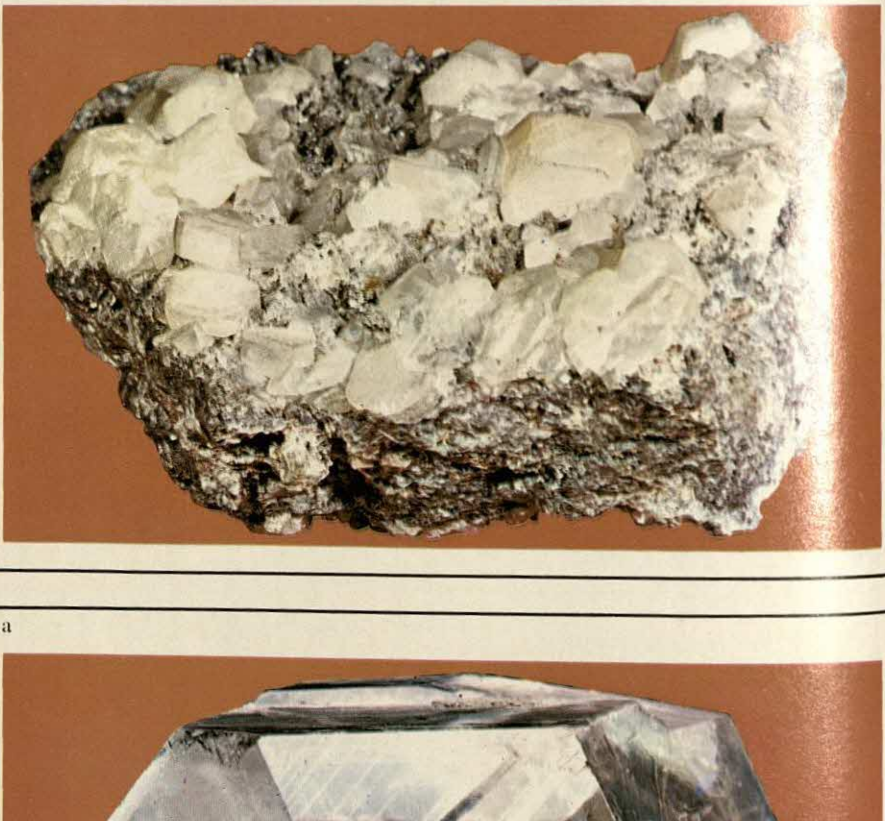
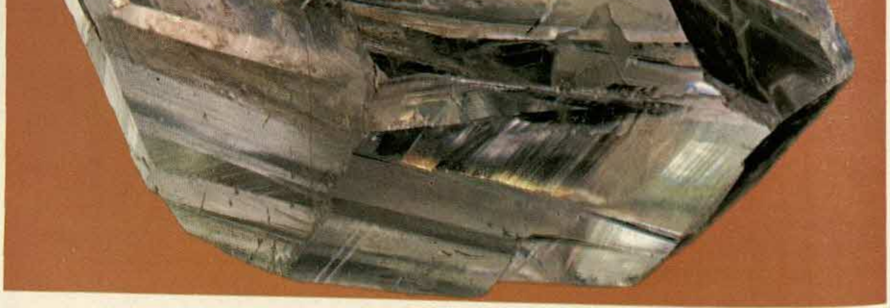


2

EXCEPTIONAL CALCITE CRYSTALS—Calcite crystals as perfectly formed as those shown in Illustration 2 are quite rare. Pure calcite (Illustration 2a), a form of transparent spar, can sometimes be found in dolomitic rock. This monocrystal has a number of characteristics: a rhombohedral form with striations of the faces, and a certain amount of cleavage parallel to the crystal faces. These cleavages appear to be fissures starting on the surface of the crystal.

The quartz geode shown in Illustration 2b contains icy-looking calcite crystals; such a geode is exceedingly rare.

a



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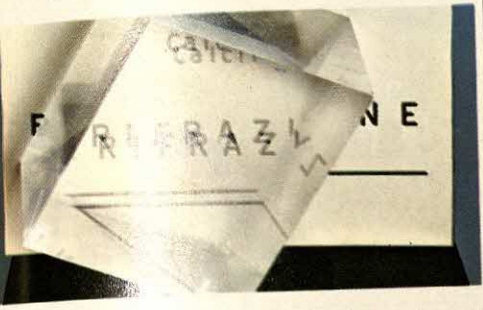


ICELAND SPAR—Pure calcite, in the form of Iceland spar, is almost impossible to find in the field. Therefore, a collector must usually rely on dealers as his source.

This illustration demonstrates the property of double refraction possessed by Iceland spar. To achieve this, a specimen must be worked with care to expose clean faces. It is inadvisable to work the specimen with pitch and abrasives because the mineral is very soft, is easily scratched, and is difficult to polish.

THE COMMON FORMS OF CALCITE—Not only is calcite a very common mineral, but many rocks are composed of almost pure calcium carbonate. However, traces of impurities—often as small as one part per thousand—are sufficient to render the crystals opaque. In rock such as marble, moreover, calcite is found in the form of microcrystals, because the mineral was forced to grow in close proximity to other crystals.

In many rocks, however, it is not unlikely that a chance event allowed a few crystals to grow unhindered. Such occurrences result in crystals much larger than average, and it is these crystals that interest the serious collector. Completely "free" crystalline forms can be found in geodes or on the surface of a druse.

A particular form of calcite can be found in caves as a result of the deposition of the mineral from calcareous water. Stalactites and stalagmites are at times large-grained polycrystals of calcite. The calcite crystals shown in Illustrations 1a and 1b grow freely, but trace impurities make them opaque.

b

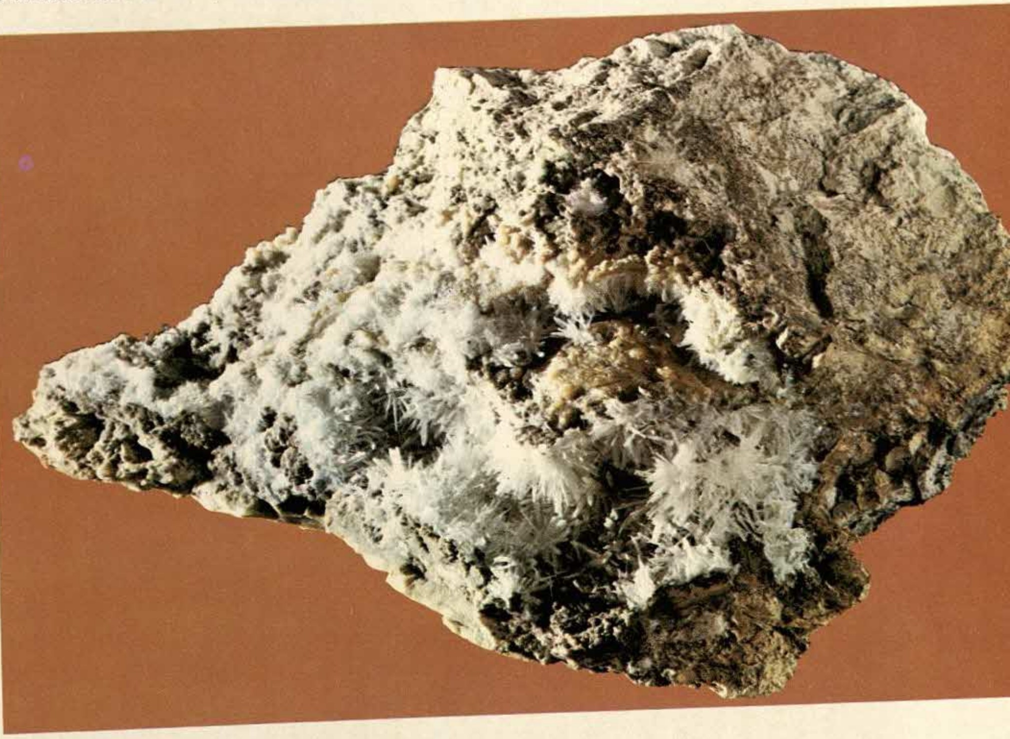
4

ARAGONITE—This mineral represents the other form taken by calcite. Aragonite is composed of orthorhombic crystals, and unlike calcite, it is not subject to cleavage. It is also attacked more readily by hydrochloric acid than is calcite. The elongated crystals of aragonite are often arranged in a radial pattern.

The specimen shown in Illustrations 4a and 4b consists of needle-shaped crystals attached to a variety of serpentine. In fact, this sample comes from the contact point between a system of serpentines and a mass of dolomite. The detail in Illustration 4b gives a perfect view of the structure of aragonite crystals.

An aragonite crystal such as that in Illustration 5a (p. 38) is a rarity. The most likely spot to find a specimen such as this is in a cavern where a chance occurrence has made

a



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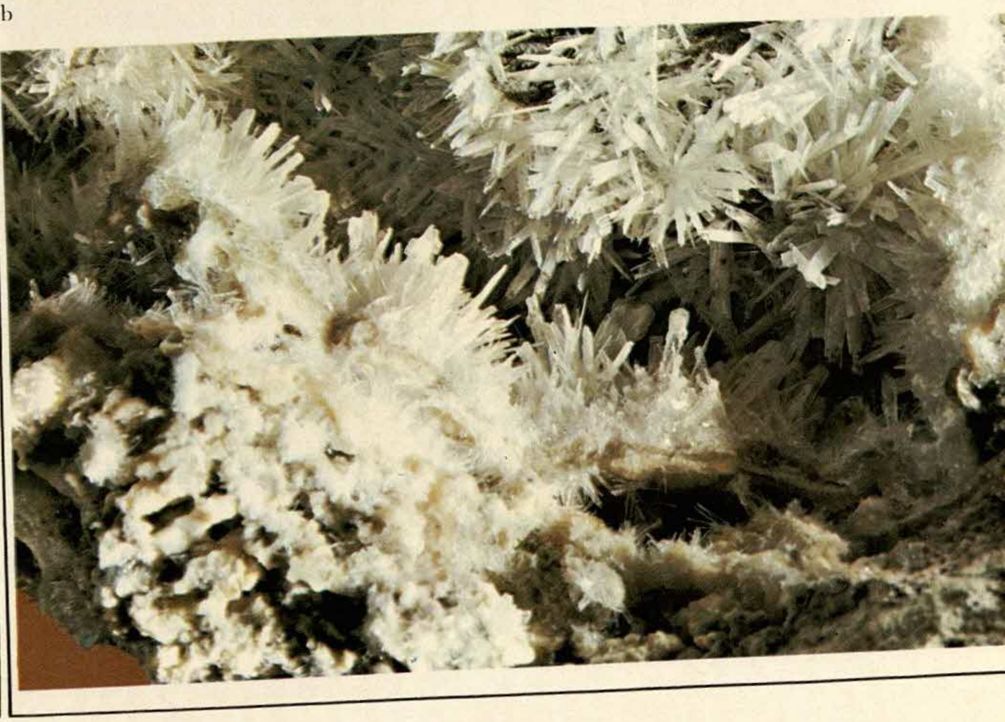


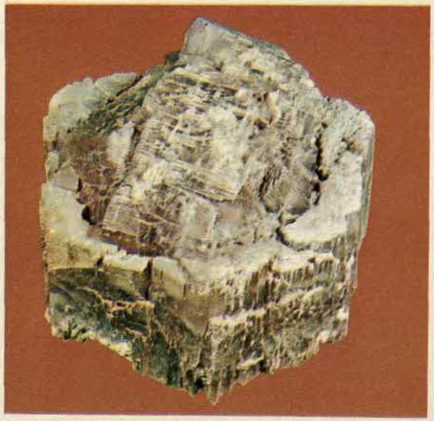
5

possible the formation of aragonite rather than calcite.

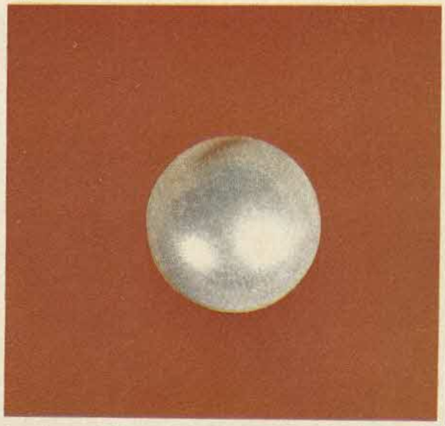
Similarly, these remarks apply to flos ferri ("flower of iron") the arborescent variety of aragonite shown in Illustration 5b. Beautiful concretions such as this do not display normal crystals, since they have been distorted by some means during growth.

Illustration 5c is also aragonite, this time in the form of a pearl. The inorganic secretion with which mollusks seal their wounds, and in the process form a jewel, is nothing more than a microcrystalline aggregate of aragonite. Oysters are not the only sea creatures to form pearls; small pearls are often found in other mollusks. Therefore, pearls have a justifiable place in a mineral collection as aragonite of biological origin—as are seashells.

a



c



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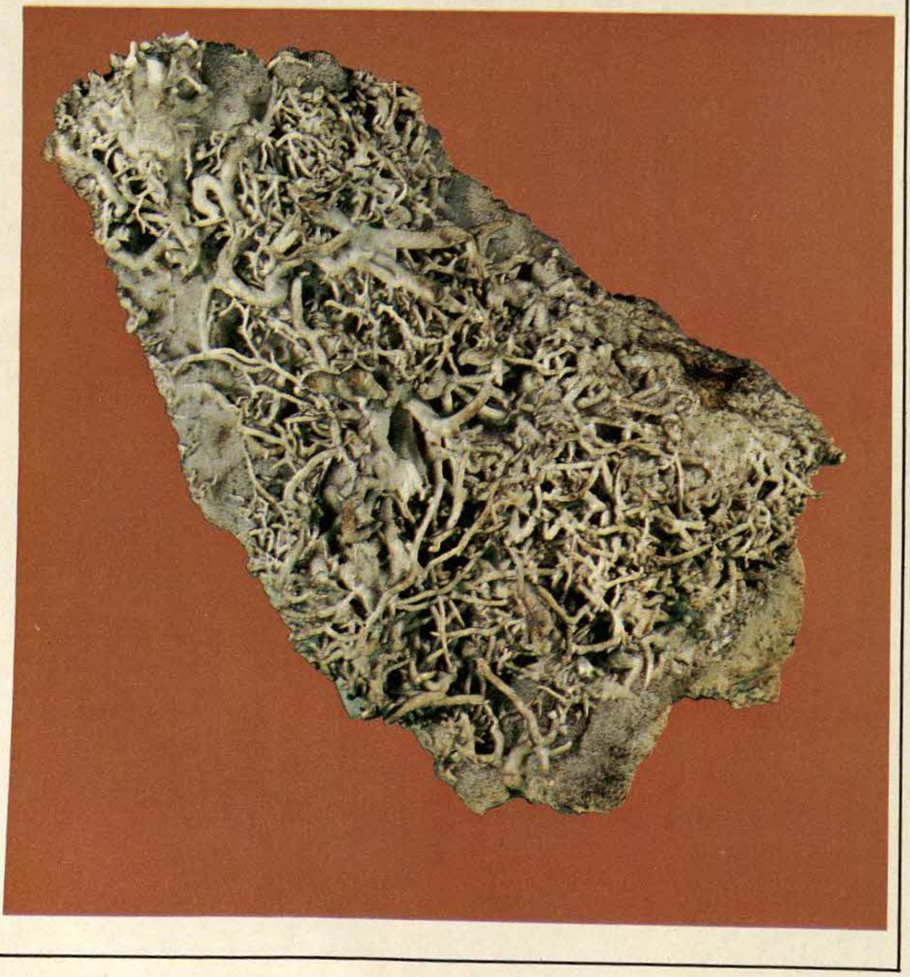


6

7

HYDRATED COPPER CARBONATES— Hydrated copper carbonates are of hydrothermic origin, and the finest specimens are used for jewelry. Among these are malachite and azurite.

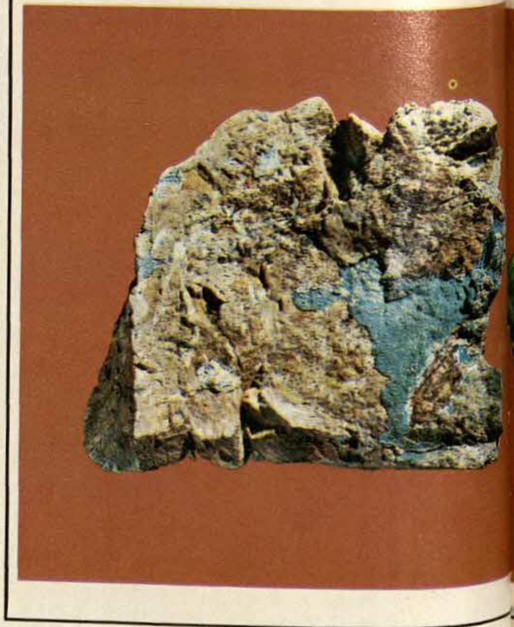
Malachite is formed as a result of the weathering of copper sulfides, which are first oxidized to sulfates. The subsequent action of bicarbonate-bearing water leads to the formation of the hydrated carbonate, $CuCO_3 \cdot Cu(OH)_2$. An excess of bicarbonate carries this process further, resulting in azurite, Cu[illegible]$O_3)$ $(OH)_2$.

The green sample of malachite shown in Illustration 7a has formed a crust that has permeated a fissure in the parent rock.

The greenish-blue malachite in Illustration 7b is associated with bornite and chalcopyrite, two copper minerals that are raw materials for malachite formation. Therefore, this specimen is particularly interesting because it illustrates the history of the principal mineral.

The characteristic form of semiprecious malachite, as seen in Illustration 7c, merits the collector's special attention. It tells the story of its own creation through a deposition of successive layers. In cross section, such a concretion exhibits the variegated patterns responsible for malachite's beauty. As such, this mineral is prized as a semiprecious stone.

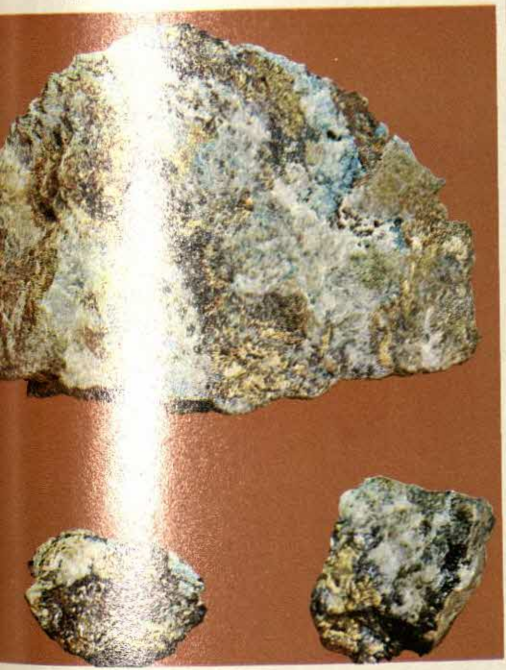
a



IRON CARBONATE—Also known as siderite or spathic iron, iron carbonate is of interest both to the collector and to the ferrous metals industry where it is an important ore for the production of the primary metal.

Iron carbonate is often associated with calcite, is sometimes transparent, and may be covered with a dark patina. Specimens can be easily found in mine tailings or in veins embedded in outcroppings along mountain roads in the vicinity of iron mines.

b



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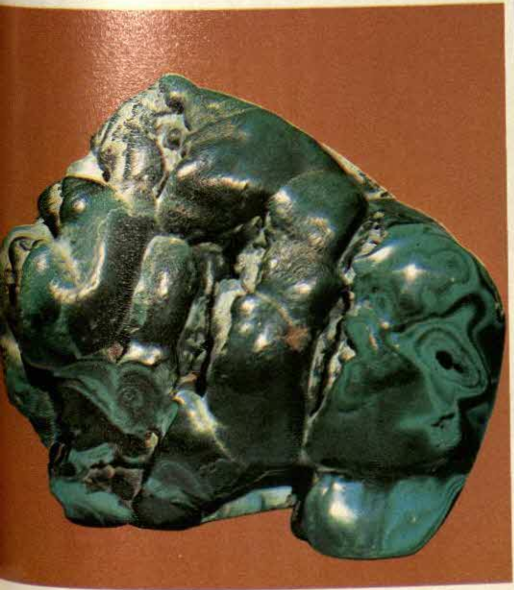

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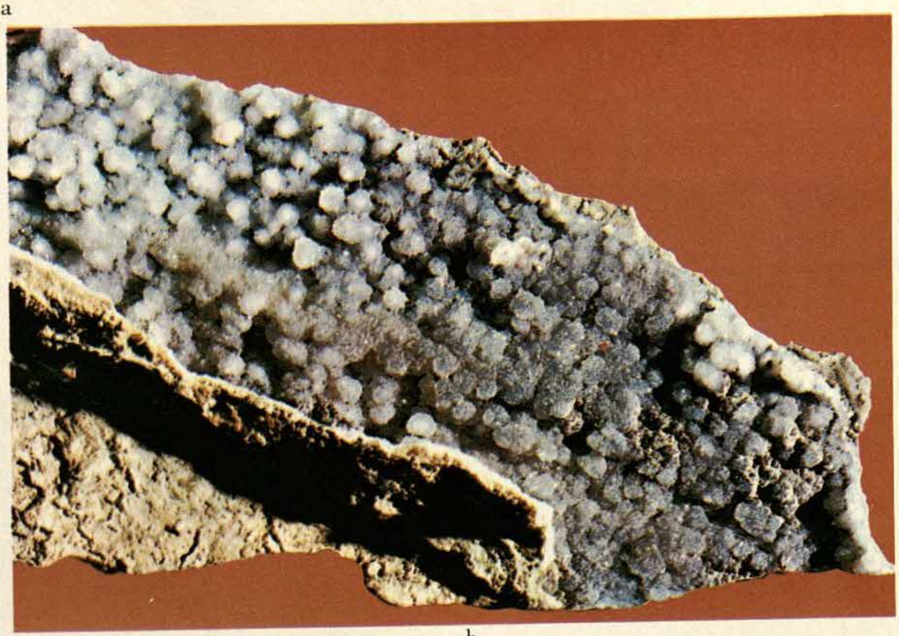
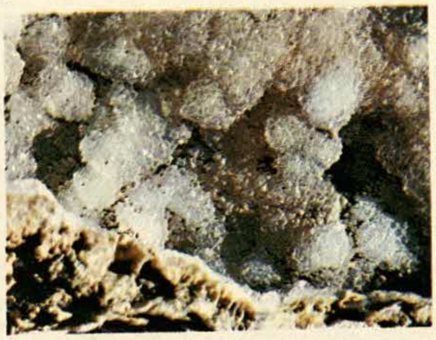


8

HYDRATED MAGNESITE—Because hydrated magnesite is classified as a relatively rare mineral, it is worth adding to any collection. The mineral is formed by the weathering processes on serpentine rocks (basic silicates of iron and magnesium). The specimen in Illustrations 8a and 8b (detail) is a concretion that has partially filled a large fracture in the mother rock, forming a kind of geode. The crystals have a lamellar form and are grouped so as to form small spheres.

The detail of the specimen in Illustration 8b clearly shows both the form and arrangement of the crystals. Note the transparency and ice-blue color characteristic of magnesite.

b



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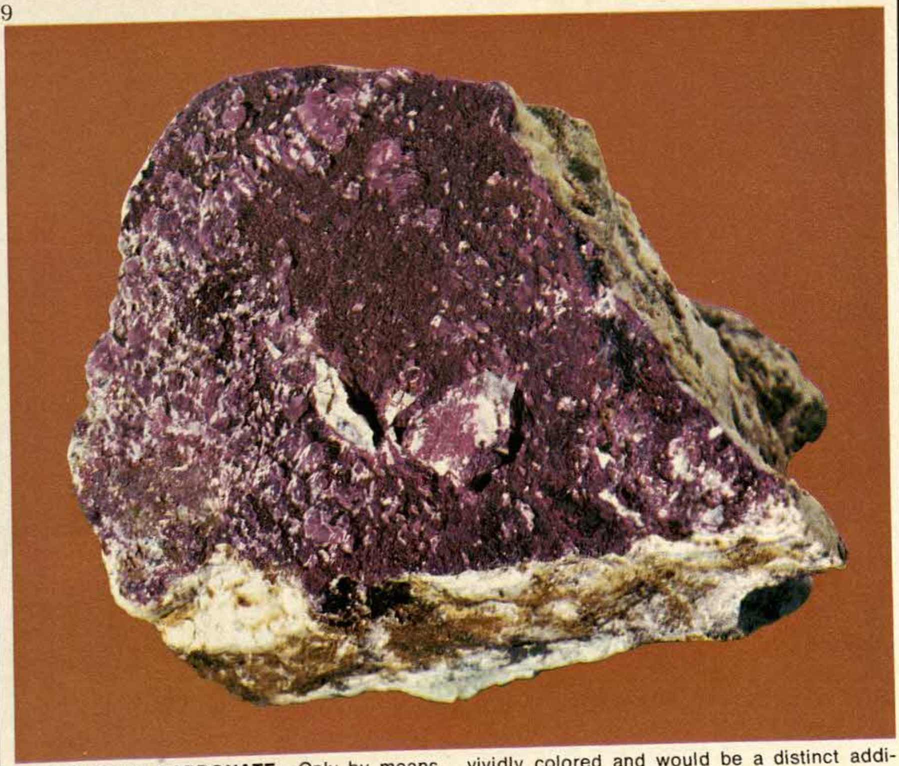


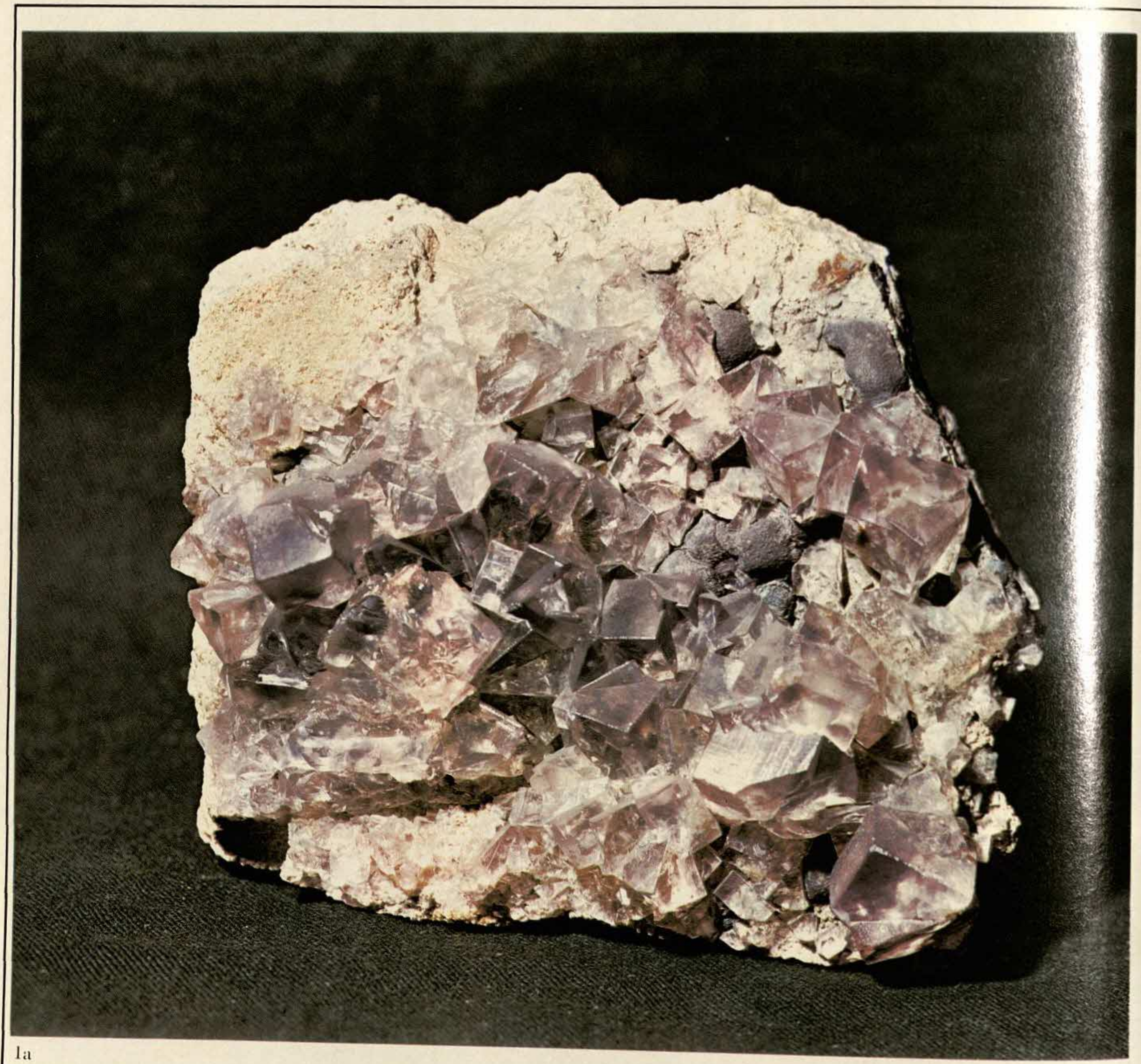
A VERY RARE CARBONATE—Only by means of prolonged and careful searching can a sample of cobalt carbonate be found. As is typical of cobalt compounds, this mineral is vividly colored and would be a distinct addition to any collection. This specimen of cobalticalcite was found in Katanga, in the Democratic Republic of the Congo.

HALOGENIDES AND SULFIDES

fluorescence and "fool's gold"

In almost endless variety, nature's minerals offer themselves to the collector. In fact, because of the great variety and wide distribution of minerals, serious collectors have a reasonably good chance to find and catalog new kinds of minerals.

To help the amateur mineralogist, some publications dealing with crystallography contain information on the steps to be



1a

BEAUTY AND FRAGILITY—Fluorite, or calcium fluoride, is quite fragile and can be readily flaked. These characteristics notwithstanding, this mineral is important for its extremely low index of refraction. In fact, with an index of 1.43385, fluorite has one of the lowest indices among the natural crystals.

Fluorescence was first observed in this mineral, and the phenomenon derives its name from the name of the mineral. When irradiated with x-rays, fluorite displays an intense bluish fluorescence.

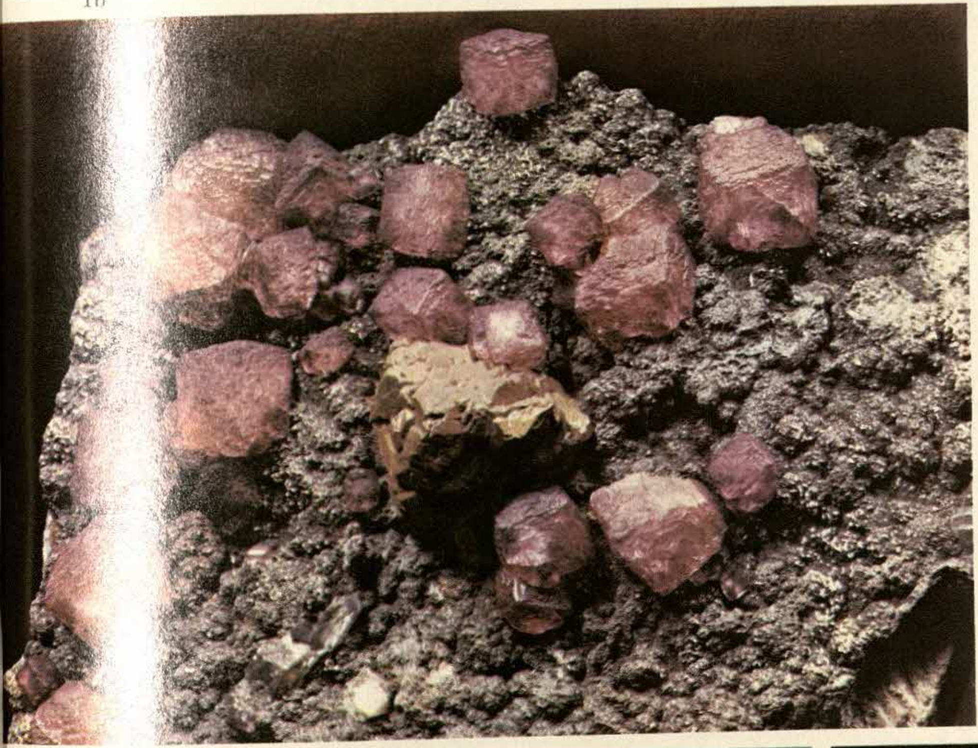
In addition to its fragility, fluorite is quite sensitive to temperature changes. Therefore, large specimens must be protected from thermal shock in order to avoid fracture.

The fluorite sample in Illustration 1a provides a good example of the mineral's low index of refraction. The cubic crystals, tinged a delicate violet, are almost totally transparent; the mother rock is visible directly through them. This property of transparency makes fluorite useful in the manufacturing of small objectives for microscopes. Even a slightly tinged fluorite can be used for this purpose, as any color is barely discernible because of the thinness of such lenses. Presently, synthetic materials are replacing the use of natural fluorite in this capacity.

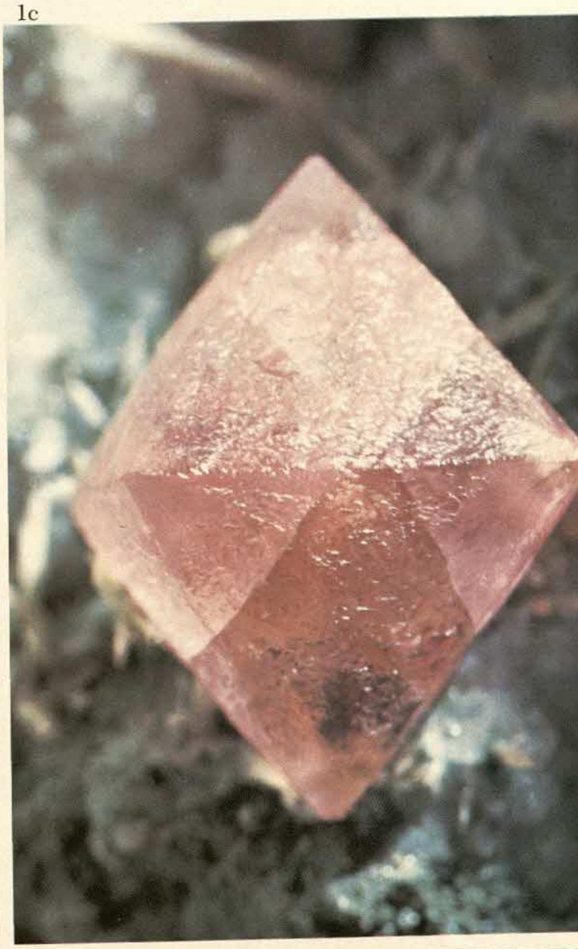
Illustration 1b shows other features of fluorite. Its reddish-pink color is apparent, as is the cubic formation of the crystals. On some of the cube faces, the terracing has tended to give the crystals an octahedral shape. Cubes with faces on the order of 20 cm (about 8 in.) on a side have been found.

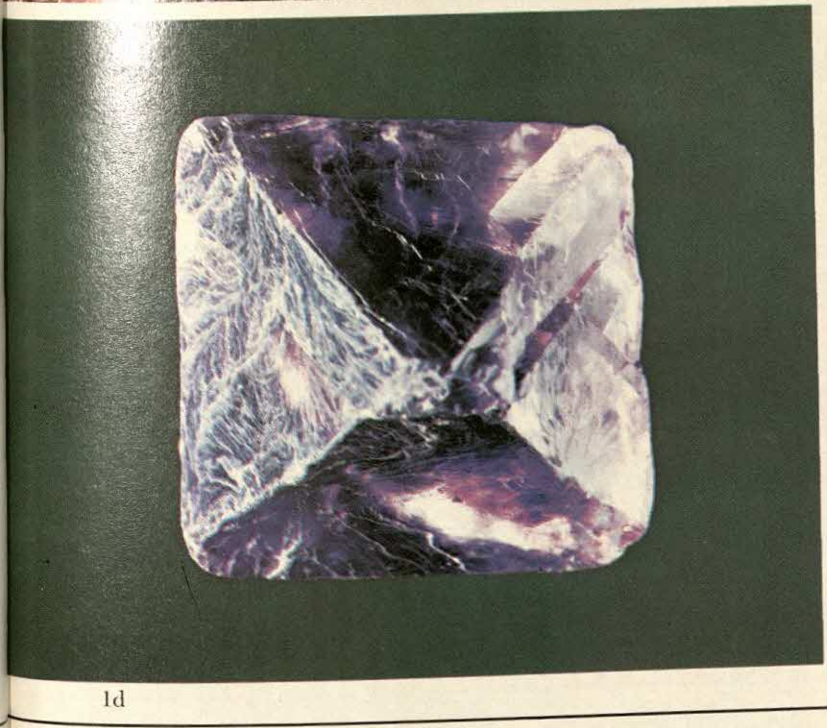
The fluorite samples in Illustrations 1c, 1d, and 1e clearly show the octahedral crystal structure. The transparent violet crystal in Illustration 1c has a number of fractures and striations in planes parallel to the faces. The smoky hue of the crystal in Illustration 1d is the only important difference between this sample and that in Illustration 1c. Cleavage lines and a bright pink color form a strikingly beautiful crystal in Illustration 1e.

1b

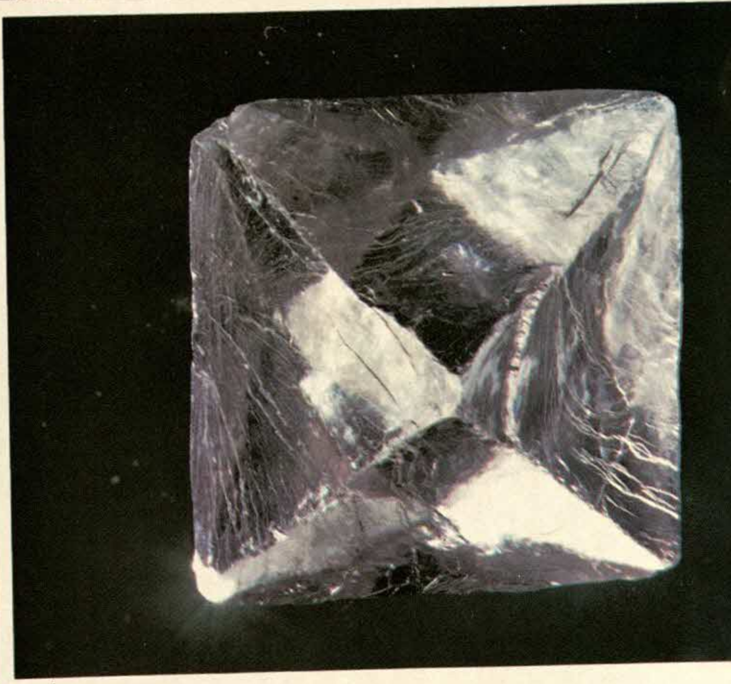


1c





1d



1e

ROCK SALT—From a geologist's point of view, rock salt is a particularly interesting mineral. Its origins are simple. Rock salt is produced by the evaporation of seawater. If the mineral is protected from subsequent dissolution by overlying sediment, it forms more or less permanent crystals. The sodium chloride formed in this manner may react chemically with surrounding minerals.

Often, hydrocarbons are found closely allied to rock-salt deposits—probably due to the lagoon origins of the salt formations—and geologists have been able to establish the presence of rich oil fields in the vicinity of rock-salt deposits.

Thus, rock salt may be found in two principal forms: that deriving from direct deposition of the mineral; and that resulting from subsequent chemical changes. In the second case, it is possible to find isolated, perfect crystals. The sample in Illustration 2 is of primary rock salt. Although cubic, transparent crystals of this mineral add much to a collection, the fibrous structure of this sample, with its pinkish-brown color, is of great interest.

2

followed in describing a new "find." The primary aim of such information is to establish that a discovery is truly authentic and has not already been made. Second, a new mineral must occur with sufficient frequency so as not to be considered a unique specimen. Once these facts have been established, there are still other requisites with which a new mineral must comply before it can be universally recognized as a new discovery.

The work of amateur collectors is very important in cataloging new species, for there are far more nonprofessionals in the field than experts. However, before anyone can claim proficiency as an amateur mineral prospector, he must have a solid knowledge of minerals. The easiest way to gain proficiency is through the collection of as many specimens as possible, while at the same time studying the characteristics of each species; pure metals, carbonates, silicates, and sulfides, for example.

The halogenides are minerals containing fluorine, chlorine, bromine, or iodine. Among these, fluorite is the principal fluoride mineral. In sulfide minerals, sulfur is combined with a metal or semimetal. Pyrite is by far the most common sulfide mineral, and is an important ore of sulfur. Pyrite is sometimes mined for the gold or copper that may be associated with it. Both the halogenides and sulfides are important to the collector and to industry, each in its own way.

CRYOLITE—This rare mineral (Illustration 3) is found only in a few places, primarily in Canada, Greenland, and the Soviet Union. It has importance in the aluminum industry, and it can be produced synthetically. Its properties are similar to those of fluorite.

THE MOST COMMON SULFIDE—Iron sulfide, or pyrite, is the most abundant and best known of the sulfides. One of its popular names, "fool's gold," is derived from its resemblance to gold. Industrially, this mineral is exploited in the production of iron and sulfuric acid.

Pyrite occurs in igneous rock, crystalline schists, and sedimentary deposits, especially when they have been affected by hydrothermal activity (pyrite crystals have been found in marble). The specimen in Illustration 4 is of the cubic variety.

A totally representative collection of pyrites would include varieties obtained from different locations, each associated with a different parent rock, and preferably with a description of the process that led to its formation. For example, deposition at elevated temperatures followed by rapid cooling leads to the formation of cubic crystals. Lower temperatures during the stages of formation, on the other hand, result in crystals of octahedral structure. Such crystals, however, are rarely found.

Other interesting and rare pyrite specimens are those in which the mineral occurs in sedimentary rock. Finds such as these are associated with fossils; some specimens actually replace fossils. For example, ammonites may be found in pyrite, as can the fossil remains of echinoderms. Both instances illustrate the hydrothermal formation of the mineral.

COMPLEX SULFIDES—Similar in appearance to a gold nugget, the chalcopyrite sample in Illustration 5a is really a sulfide of iron and copper. This mineral is sometimes known as copper pyrite, yellow pyrite, or yellow copper ore. In this specimen the mineral is in association with small quartz crystals. About 80 percent of the world's copper is mined from chalcopyrite deposits.

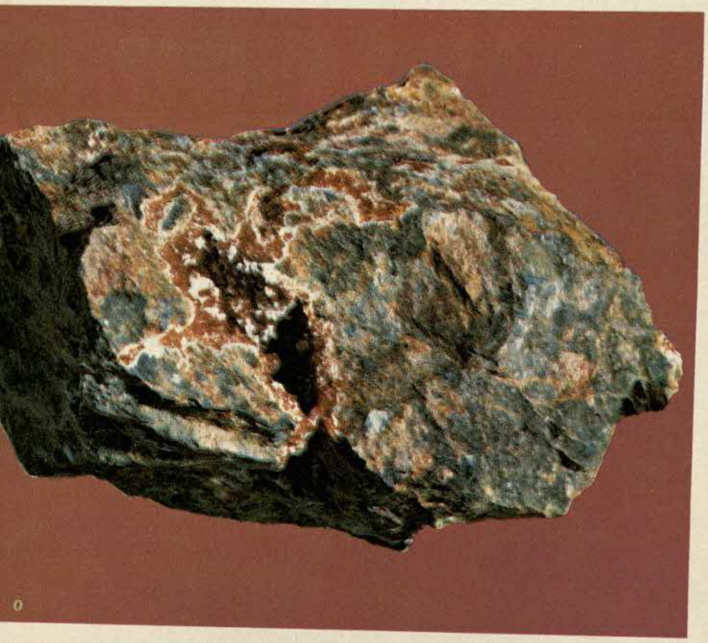
The specimen in Illustration 5b is arsenopyrite. It is often associated with gold, but more commonly occurs with ordinary pyrite in metamorphic rock. In the latter instance, formation occurred either by deposition of magmatic gases or hydrothermally. The arsenopyrite in this specimen forms the base material in which quartz crystals are embedded. The sulfide itself crystallizes in the form of monoclinic prisms.

Illustration 5c shows a sample of stannite, a complex sulfide of tin, iron, and copper. In certain areas of the world, stannite deposits are rich enough to be exploited for the tin content. The sample here clearly shows the characteristic gray color of this mineral. The crystalline formation, though appearing to be cubic, actually forms part of the scalenohedral, tetragonal class.

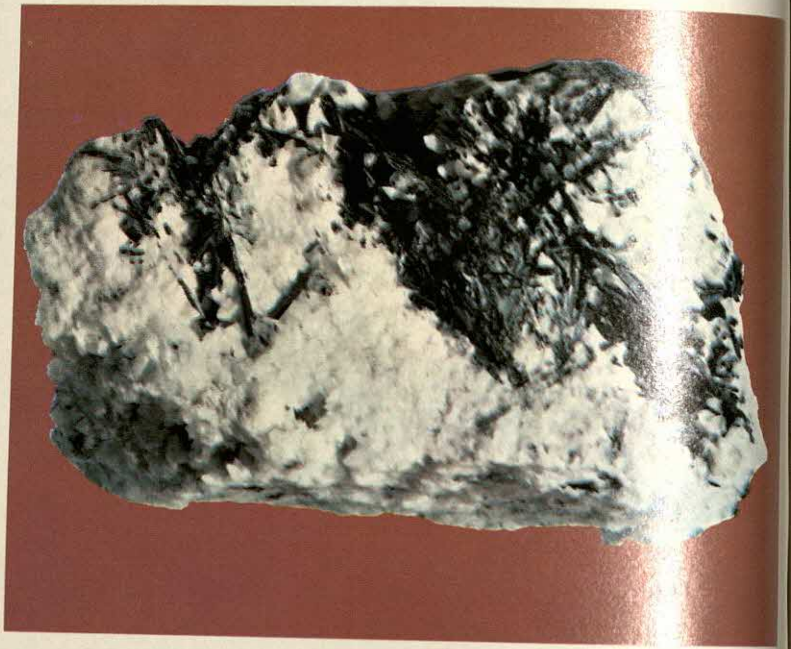
4

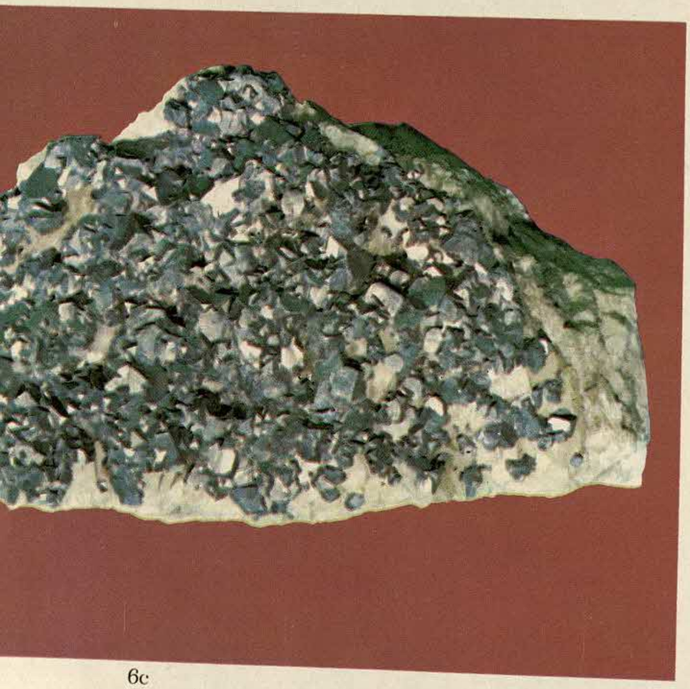
5c

6a

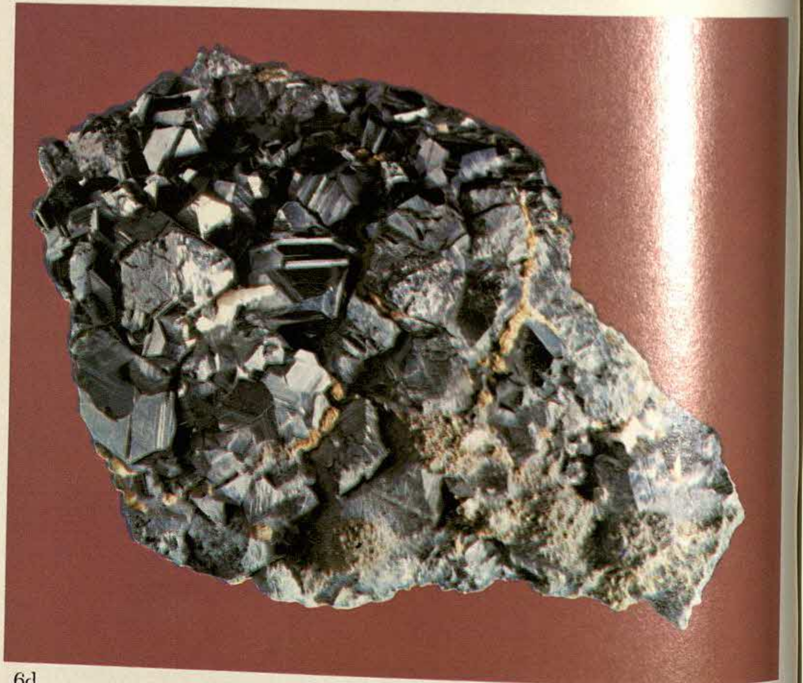


6b





6c



6d

FOUR COLORFUL SULFIDES—Cinnabar, or mercury sulfide, is another well-known sulfide, and is characterized by its vivid red coloring. Although the mineral crystallizes in the trigonal system, perfect crystals are quite rare. Cinnabar is the principal ore of mercury. In the Middle Ages, cinnabar was ground and used as a paint pigment. The permanence of this pigment, carmine red, is attested to in the frescoes of many medieval churches.

While cinnabar is a rather common mineral, its cousin, metacinnabarite, black in color and cubic in form, is rarely encountered.

Arsenic sulfide, known as realgar to mineralogists, has a reddish-orange color. Samples such as that in Illustration 6a were formed by volcanic action and are generally found in association with other sulfides.

Antimonite, or stibnite, is a sulfide of antimony. Its characteristic features, as shown in Illustration 6b, are a gray color and a metallic luster. In ancient civilizations, the powdered form of this mineral was used as an eye cosmetic. In contrast to fluorite, thin transparent sections of stibnite have a very high index of refraction.

Illustration 6c shows the beautiful gray-green crystals of galena, or lead sulfide. Like stibnite, it has a high index of refraction, and has the additional property of being a semiconductor. Optically, the cubic or octahedral crystals are transparent to infrared light, but opaque to visible light except when cut into thin sections.

Finally, the lustrous tetrahedrons in Illustration 6d are zinc sulfide, also called zinc blende. In many ways, this mineral resembles galena, and forms an interesting part of any collection.

OXIDES AND HYDROXIDES | colorful minerals from oxidized metals

In the Earth's crust are hundreds of minerals, each with distinct properties, but often associated with other compounds having similar composition and characteristics. Without some system of classification, mineralogy would be chaos.

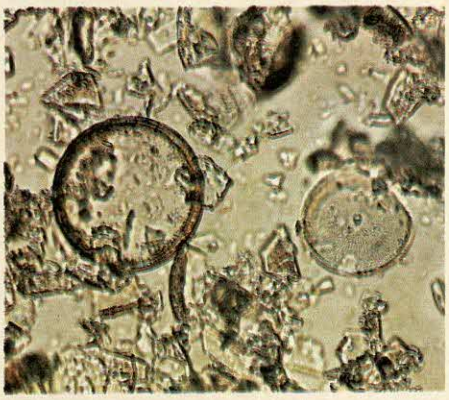
Therefore, the study of crystals—their properties and geometric structures—can be successful only through the use of *systematic mineralogy*, wherein minerals are subdivided by grouping those with similar chemical formulas. For example, it is accepted practice to study all the oxides as a group, and to do likewise for the sulfides, silicates, tellurides, and so forth. The logic of this procedure has also demonstrated its usefulness in the collection of mineral specimens in the field.

In nature, mineral specimens are more often than not found grouped together according to chemical class. In a sulfide mine, for example, while the principal compound is a sulfide of one sort or another such as pyrite, the sulfides of other elements are quite likely to be found at the peripheries of the main deposit. Such compounds are considerably less abundant than the main ore, and in most cases are not economically important enough to mine. However, they do provide a rich source for the mineral collector.

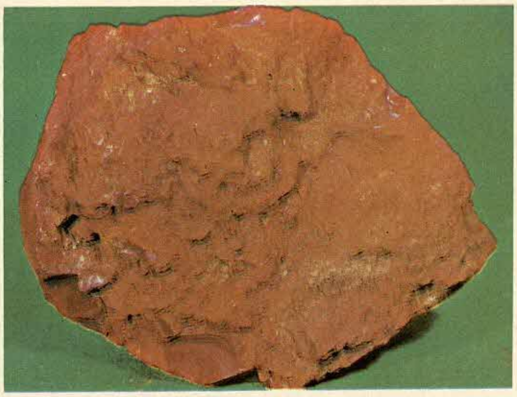
In some instances, however, an association of minerals makes their mining justifiable. Specifically, it is not at all unusual to find chemically similar minerals of lead, silver, and zinc in the same deposit. Because of the importance of each, the extraction of the less concentrated elements is usually undertaken.

Silica, one of the oxides of silicon, provides an excellent starting point for the study of minerals. This mineral is one of the most widespread in nature, and its variations make up a beautiful array for the beginning collector. Quartz is but one example of silica, and the discussion here will be devoted to some minerals that are similar to quartz, but that cannot classify as quartz crystals. Rather, such minerals possess a microcrystalline form or are colloidal, as with the hydrogels. Additionally, oxides of other elements, such as iron, aluminum, manganese, and tin, form numerous minerals of varying distribution and value.

1a



1b



1c

MICROCRYSTALLINE SILICA — Wherever igneous rocks occur (granites and diorites, for example), it is possible to find quartz. In fact, quartz is a constituent of such formations. Generally, though, it is found as small crystals of irregular form because of growth factors limited by surrounding feldspars and micas. Nonetheless, patient searching among outcroppings or in granite quarries reveals geodes and other formations where crystal growth has not been limited. In places other than quarries it is difficult to find good specimens because of damage due to weathering. However, excellent examples have been found in moraines and in the upper parts of mountain streams.

Quartzes found in igneous rock are the result of magma solidification, with the characteristic crystal formation caused by slow cooling. The silicas in the illustration, on the other hand, have an entirely different origin, having been produced by the action of water. To a very small extent, silica is soluble in water; the degree of solubility depends on the temperature of the solvent.

At one time or another, certain rocks may have been subjected to hydrothermal phenomena. In such cases, some of the silica would have been dissolved and carried away with the flowing water. In addition to dissolved silica, the hot, flowing water would in all likelihood dissolve other minerals along its course. For this reason, the silicas formed as a result of solution and deposition often display a variety of bright colors.

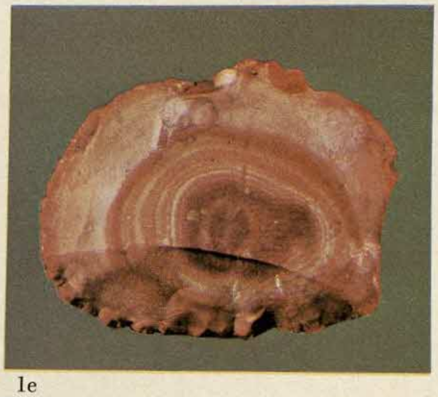
In view of the low solubility of silica, it takes a considerable amount of time for deposits to form. During this period, many changes in the composition of other minerals associated with the silica may occur. The result of such weathering is a range of color changes that give rise to elegant veining patterns in the mineral.

Generically, silica in cryptocrystalline form of hydrothermal origin is known as chalcedony, and numerous varieties of this mineral occur. The most strikingly veined types are used for jewelry and for decorative purposes. Less colorful forms have technical application, such as knife edges for analytical balances or mortars for chemical laboratories.

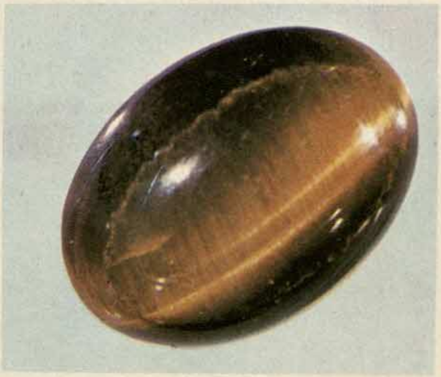
The form of silica in Illustration 1a is called fossil flour, and is often overlooked by beginning collectors. This mineral is formed of the skeletons of diatoms—sea creatures from remote geological eras. The microscope reveals the organic origin of fossil flour (Illustration 1b).

The bright red-orange color of jasper (Illustration 1c) can be attributed to iron oxide in combination with silica.

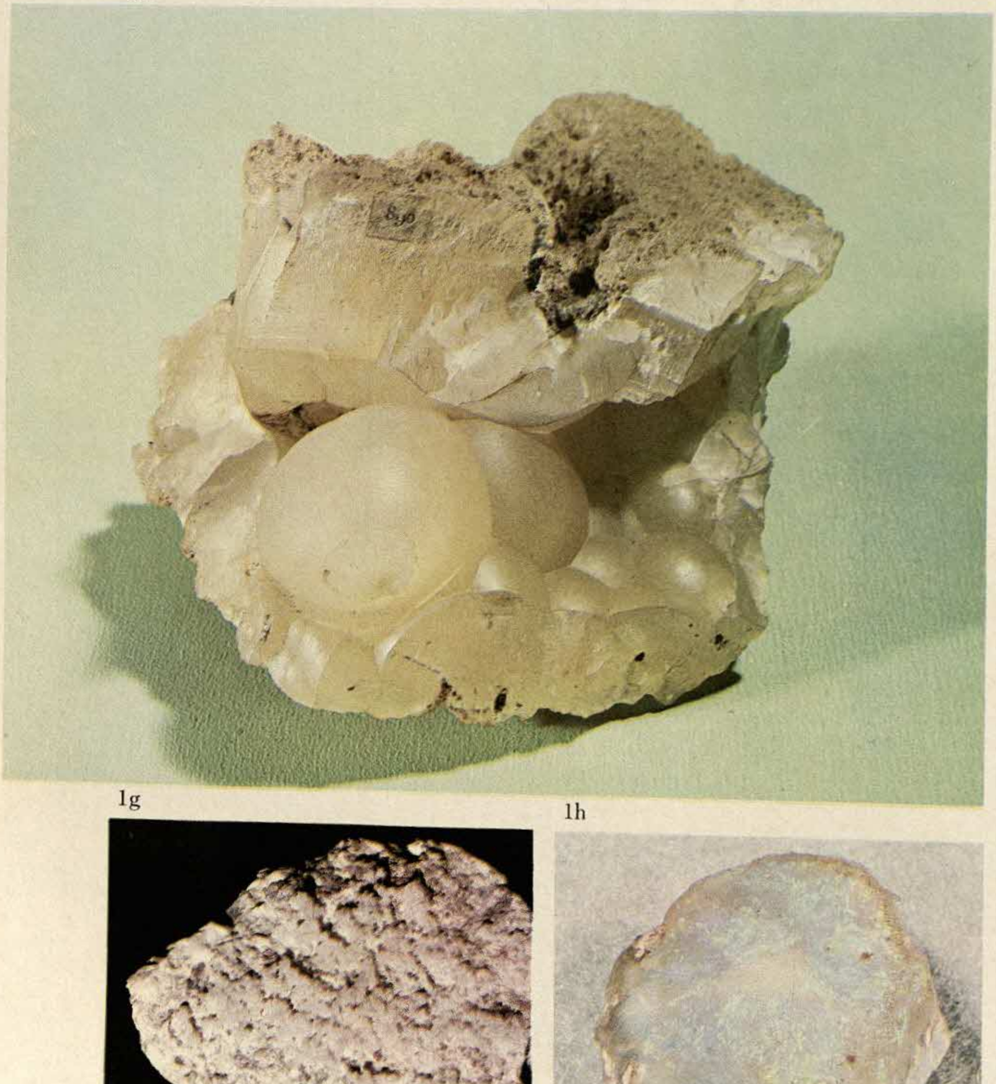
1d



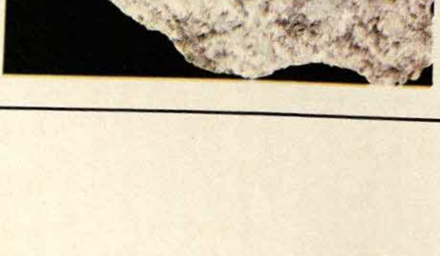
1f



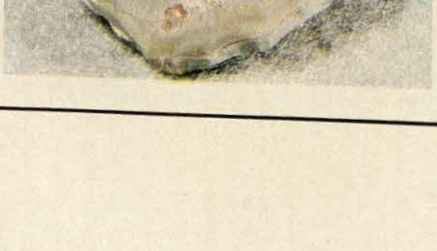
1e



1g



1h



The beautiful specimen of agate shown in Illustration 1d is a zoned form of chalcedony. When the colors are very bright and the zones sharply defined, agate is used for jewelry and cameos. Less distinct forms have technical uses.

At times, small quartz crystals may be found in the center of the variegated structure. It may even happen that a drop of the water responsible for the mineral's formation is trapped in one of the veins.

Where chalcedony deposits have been formed in comparatively soft rock, subsequent erosion often completely bares this mineral. It may also happen that the silica replaces the organic matter in fossils, particularly in the case of wood from which the famous petrified forests are formed.

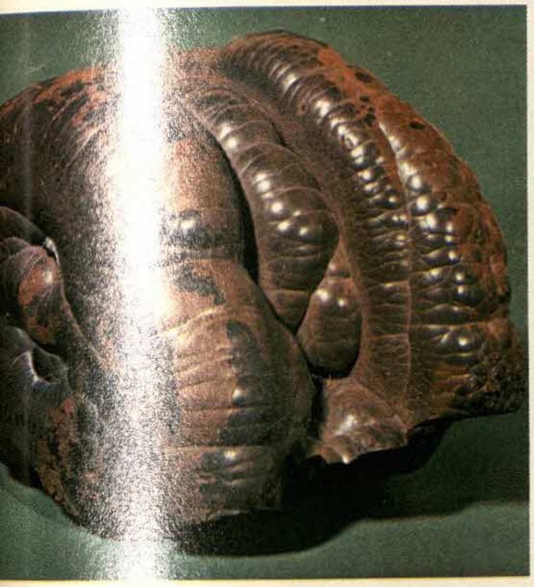
The sample of chalcedony shown in Illustration 1e comes from Iceland, and though pure cannot be used as a hard stone.

Known as tiger's eye, the example of chalcedony shown in Illustration 1f is characterized by the inclusion of crocidolite crystals (a variety of asbestos) within the silica. These crystals lie just below the mineral's surface, and its iridescent color and unusual character make it a prized semiprecious gem.

Opal, another silica, like chalcedony does not appear to have a crystalline structure. Unlike chalcedony, however, opal is amorphous even in its microscopic structure and contains varying amounts of water. It may be defined as a silica hydrogel. The opal sample in Illustration 1g is called hyalite, and by no means is as beautiful as the opal of gem quality in Illustration 1h. The latter is the most beautiful and sought-after form of opal. Its characteristic sparkle and vivid iridescence make it highly suitable for fine jewelry. Once polished and cut, this form of opal is quite expensive, but natural "rough" specimens for collections are relatively easy to find at reasonable prices.

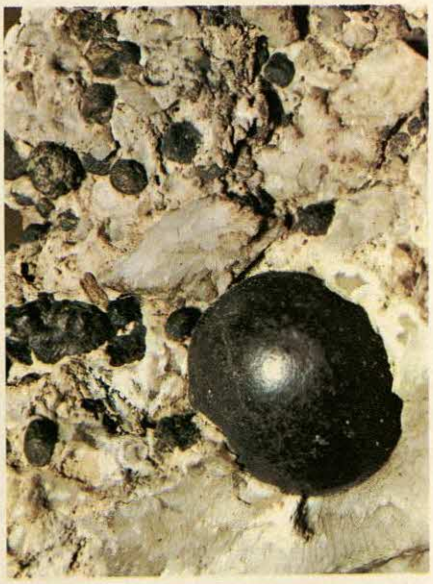
IRON OXIDES—Because of the widely distributed deposits of iron oxides, rich sources of iron minerals for the collector are usually close at hand. Thus, it is possible to amass considerable collections of these minerals with relatively little expenditure of time or money.

2a



Looking more like an anatomical specimen than a mineral, hematite (Illustration 2a) is really a sesquioxide of iron. Also called oligist or specular iron ore, it is microcrystalline with a brown or red-brown color. Its form is characterized by rounded protuberances.

2c



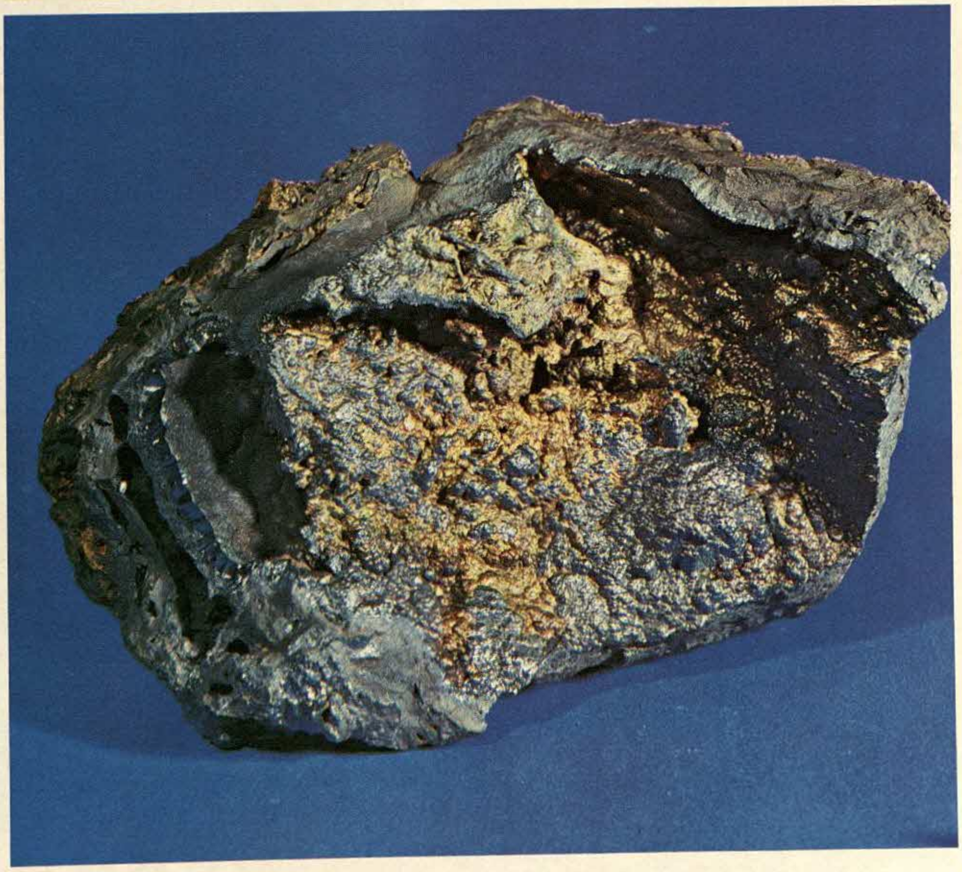
When hematite crystallizes in large crystals, it is possible to note its trigonal structure. The crystals of the sample shown in Illustration 2b overlap like the scales of a fish. Because these crystals are slightly raised, the mineral can assume the appearance of a flower. Specimens of this type, which are quite easily found, are sometimes called iron roses.

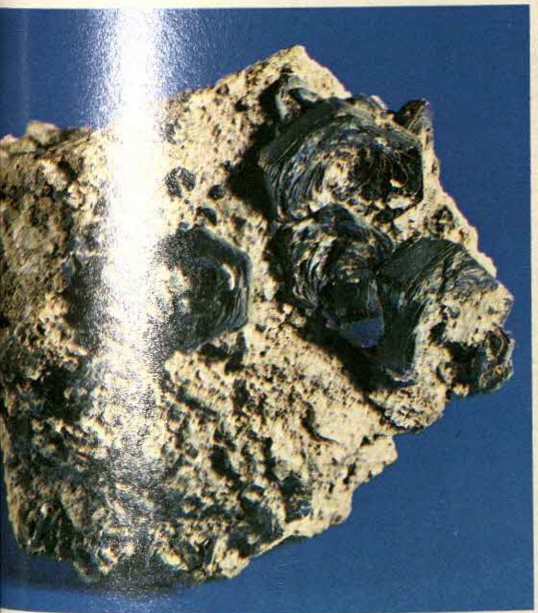
Limonite has the same chemical composition as hematite, but the iron oxide molecules in this mineral are associated with a varying number of water molecules. While the sample (Illustration 2c) is brown, a greater degree of hydration tends to form yellow limonite.

If subjected to intense heat, hydrated limonite will change from yellow to brown, more closely resembling hematite. The mineral in its brown form has been used by artists for centuries to make pigments known as siena and burnt siena.

While Illustration 2c shows a small nodule of limonite surrounded by its bedrock, the sample in Illustration 2d was found in a mine and is composed entirely of the mineral itself. Both specimens are interesting from the collector's point of view, the nodular variety perhaps more so than the latter. A limonite nodule tells the story of a formation process atypical of specimens located in the midst of a large deposit. Often, small and isolated samples of limonite are formed as a result of alterations in other iron minerals, notably the sulfides.

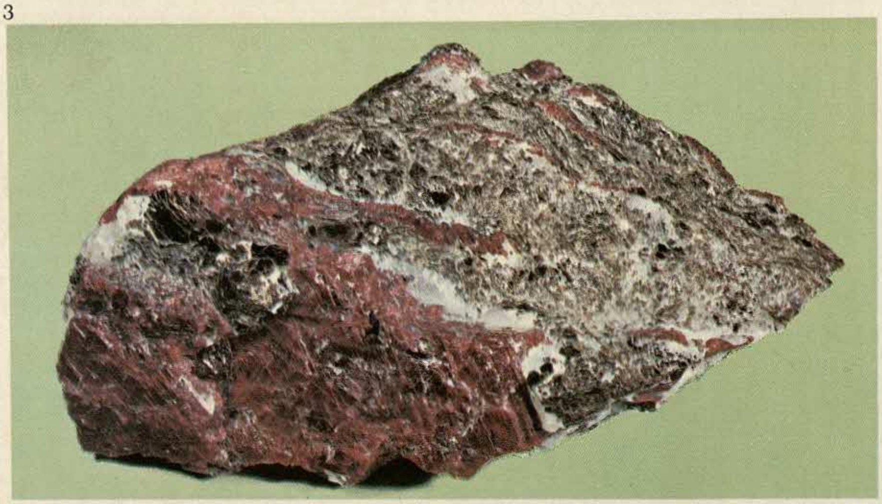
2d





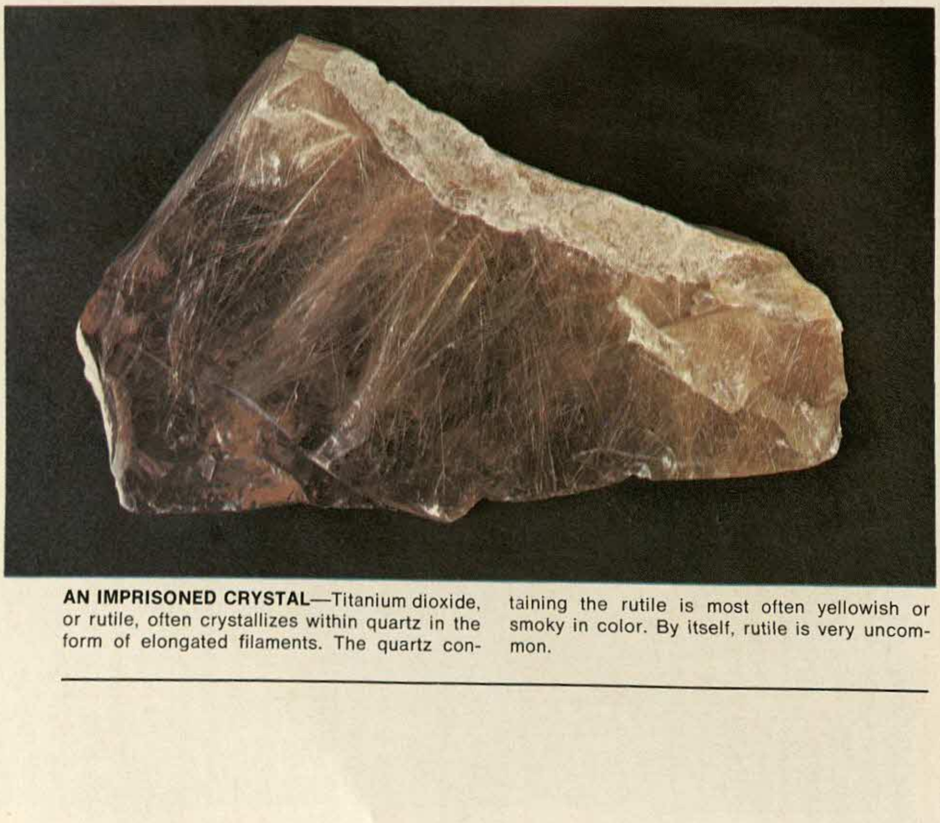
2b

3



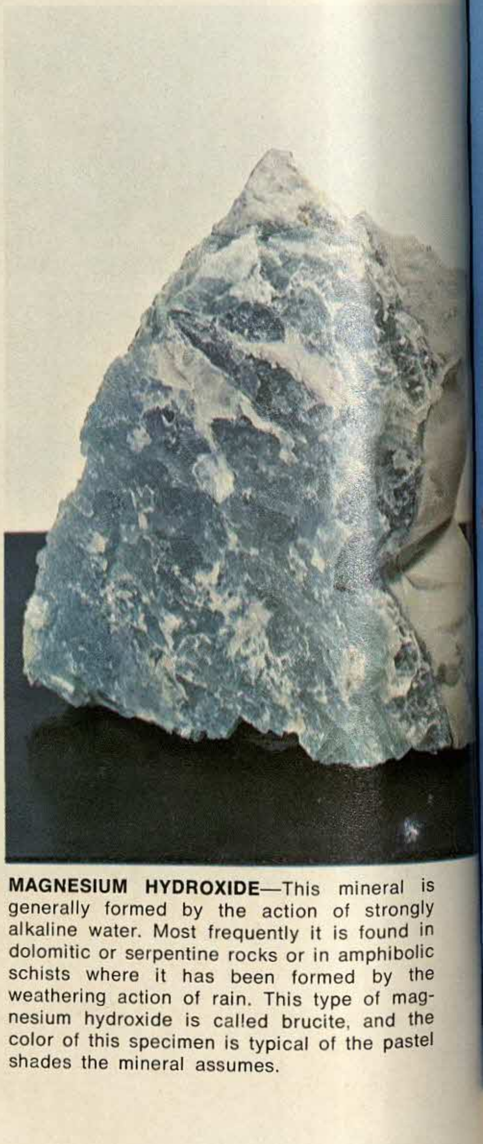
A RARE MINERAL—Corundum, a very hard sesquioxide of aluminum, occurs in a wide range of colors. When blue, the mineral is called sapphire and when red, ruby. In between, impurities within the crystal's structure impart other colors. The example in this illustration can be classified as ruby, but the crystals in this case are too fractured for use in jewelry.

4



AN IMPRISONED CRYSTAL—Titanium dioxide, or rutile, often crystallizes within quartz in the form of elongated filaments. The quartz containing the rutile is most often yellowish or smoky in color. By itself, rutile is very uncommon.

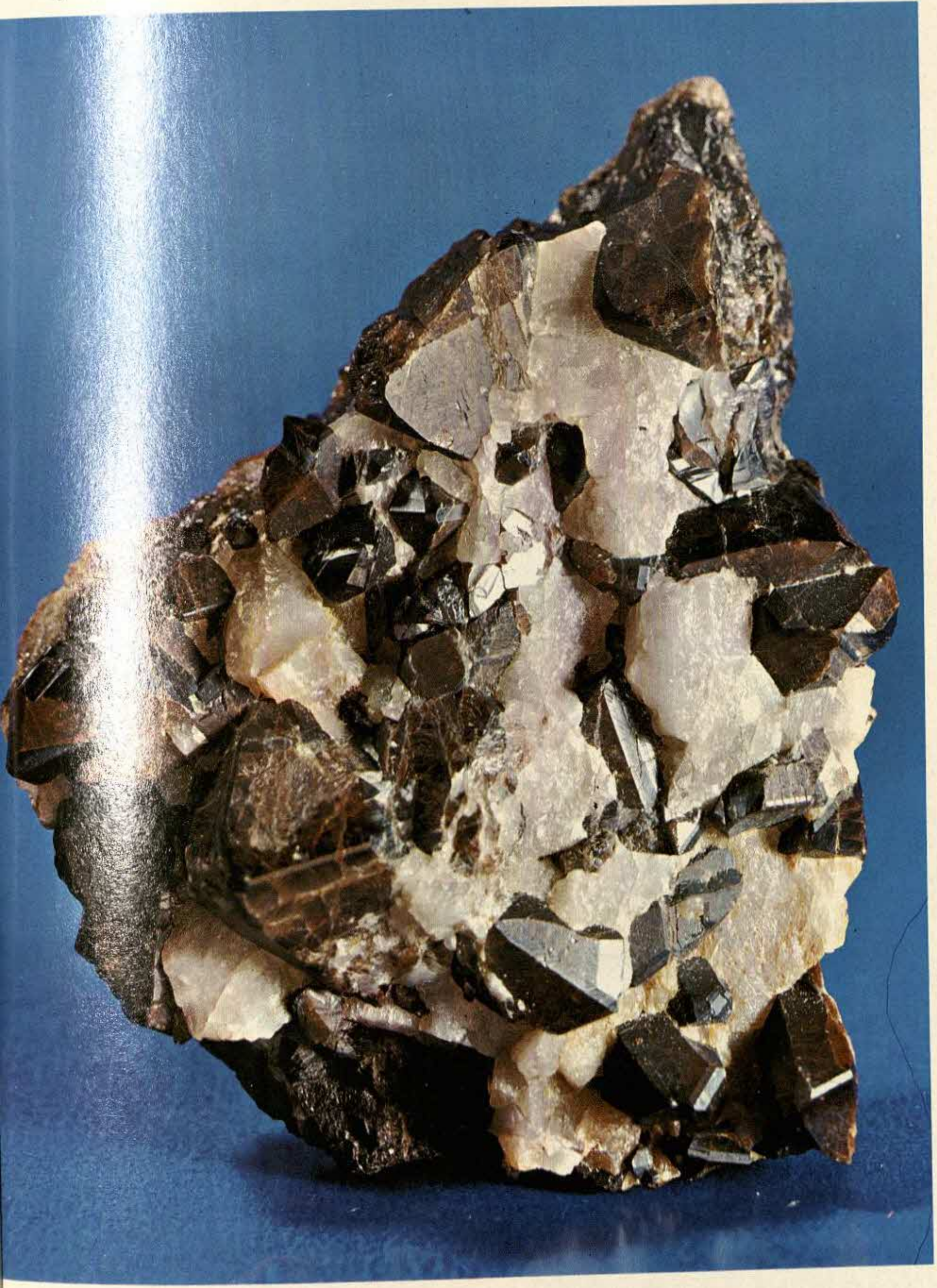
5



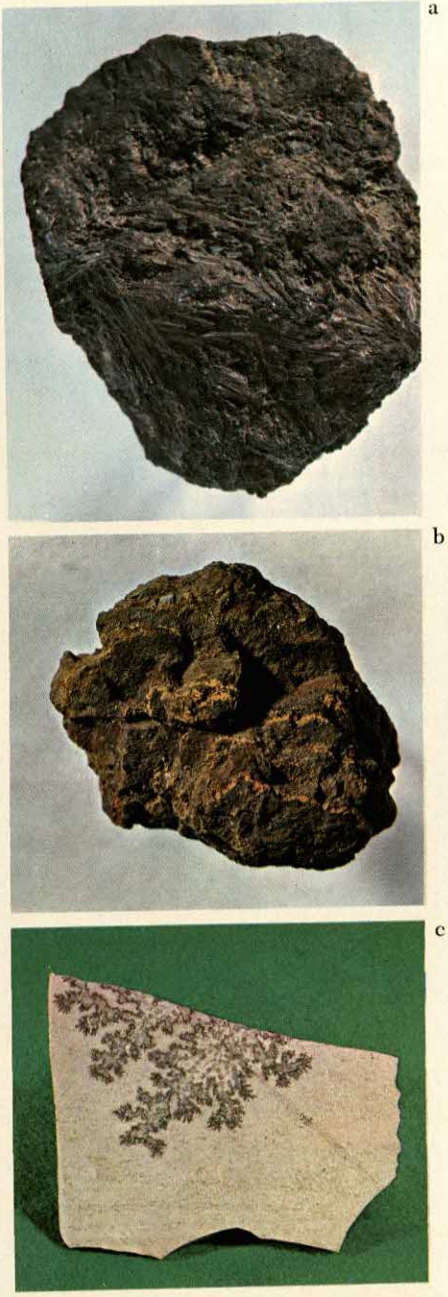
MAGNESIUM HYDROXIDE—This mineral is generally formed by the action of strongly alkaline water. Most frequently it is found in dolomitic or serpentine rocks or in amphibolic schists where it has been formed by the weathering action of rain. This type of magnesium hydroxide is called brucite, and the color of this specimen is typical of the pastel shades the mineral assumes.

CASSITERITE—Cassiterite, also known as tinstone, is a dioxide of tin, and is the most important of this element's minerals. It is the primary source for the extraction of this valuable metal. The crystals, looking something like machined metal, are associated with quartz in this example.

6



7



PYROLUSITE—A manganese oxide, pyrolusite is readily found in a very pure form. The sample in Illustration 7a is of special interest because it illustrates distinct crystals of the mineral associated in almost parallel groups. On the other hand, the form in Illustration 7b is associated with barium in the mineral called psilomelane. In this case, the rather complex mineral has formed in a deposit of clay.

In Illustration 7c, the seemingly fragile leaves are in reality dendrites of manganese oxide in sedimentary rock. Such formations occurred when, long ago, sedimentary rock was in contact with manganese dioxide or was in the path of thermal water that deposited the dioxide in cracks. Specimens of dendrites can be found by sharply striking sedimentary rocks with a hammer at the point where dark traces are seen.

MARBLE AND BRECCIA | the beauty of aged rocks

The beauty of marble has long made it a favorite of architects and sculptors. Geologists classify marble as a metamorphic rock composed originally of calcareous limestone. Therefore, like most sedimentary rocks, marble originated at the bottom of the sea. It developed its characteristic appearance when it rose above the waters and became subjected to many alterations, sometimes gaining new and brilliant coloration in the process.

A number of Greek and Italian statuary marbles famous from antiquity are still quarried. These include the Parian marble, the Pentelic marble of Attica—in which Phidias, Praxiteles, and other Greek sculptors worked—and the white Carrara marble used by Michelangelo

1

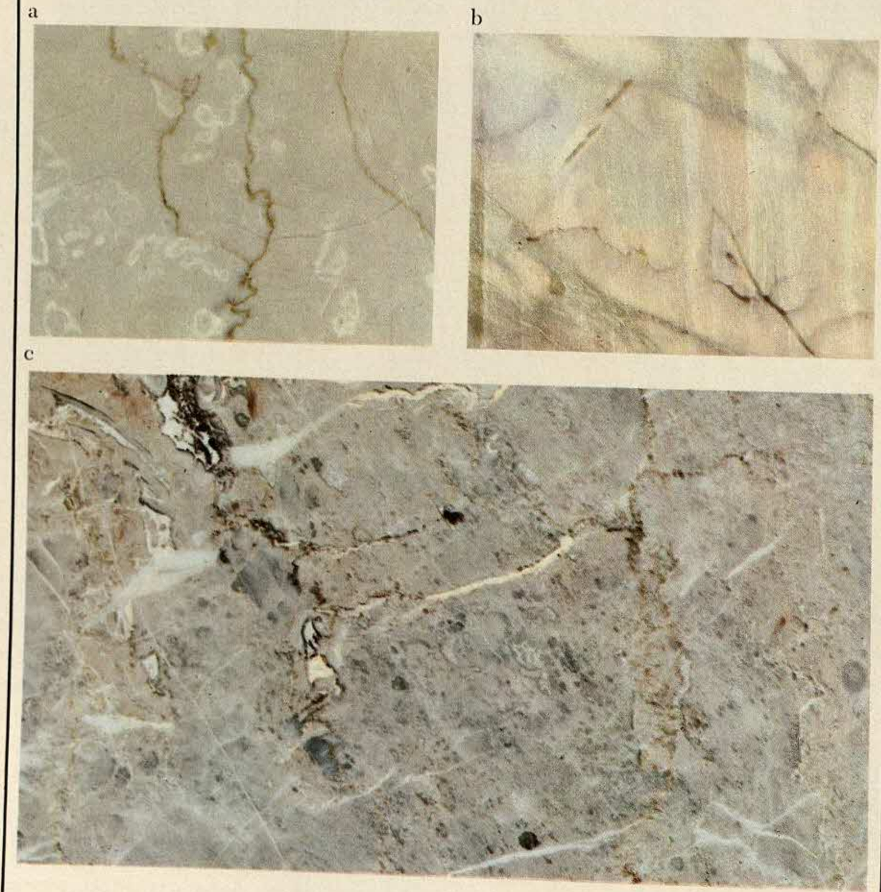
SLIGHTLY ALTERED MARBLES—Marble takes on its characteristic appearance only after it has been smoothed and polished. Shown are three specimens of marble that have undergone varying degrees of alteration. That in Illustration 1a is practically free of imperfections; the specimen in Illustration 1b is streaked with veins and fractures; the sample in Illustration 1c is considerably more altered than the other two. In statuary, pure white marble with no imperfections is sought; this type, unfortunately, has now become impossible to find except in relatively small blocks. With the opening of new quarries, however, new deposits may be found.

Marbles are often identified by local names based on the area where they are mined, their color, and so forth.

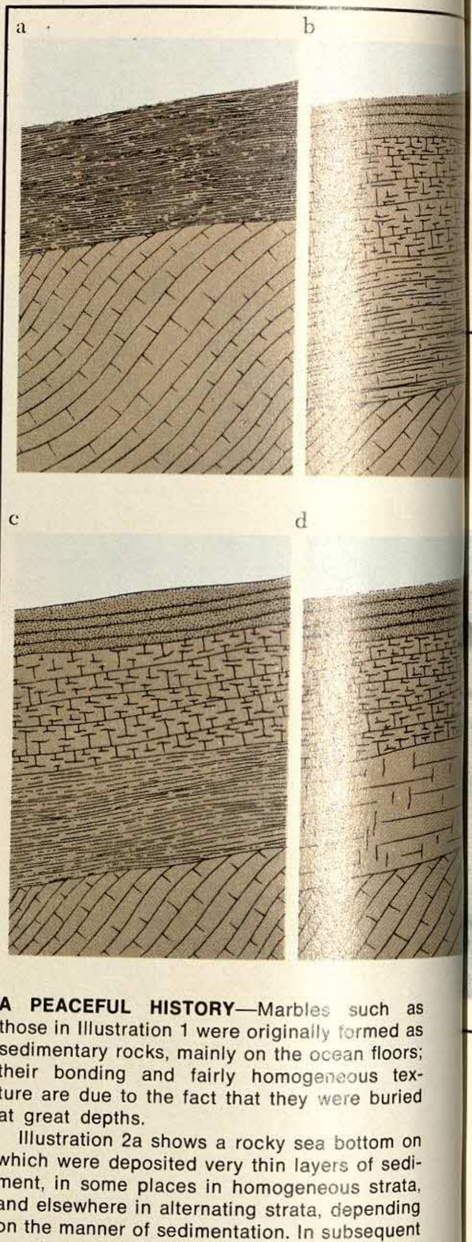
The marble in Illustration 1a is classic botticino, a very homogeneous limestone in which the only imperfections—very delicate ones at that—are rust-colored veins produced where water containing dissolved iron salts has infiltrated or has oxidized some mineral present in the marble. Also visible are fine veins, perpendicular to the others, filled with almost transparent calcite; such veins increase the beauty of this marble, which is used as a construction stone.

The marble in Illustration 1b is giallo di Siena, to which various impurities, mainly ferric oxides, have given veining and a delicate reddish tint. This marble is somewhat more altered than the botticino.

Flower-of-peach (Illustration 1c) is a marble of slightly bluish tint rather badly fractured; the fractures are filled with materials, mainly calcite, with many impurities imparting various colorations.



2



A PEACEFUL HISTORY—Marbles such as those in Illustration 1 were originally formed as sedimentary rocks, mainly on the ocean floors; their bonding and fairly homogeneous texture are due to the fact that they were buried at great depths.

Illustration 2a shows a rocky sea bottom on which were deposited very thin layers of sediment, in some places in homogeneous strata, and elsewhere in alternating strata, depending on the manner of sedimentation. In subsequent epochs, the layers were covered by successive sedimentation cycles after transgressions of the seas following the formation of the first sediment (Illustration 2b). Because of the great depth, the rocks were subjected to great pressures that caused recrystallization. If this occurred in materials that were almost pure, a very homogeneous and almost transparent marble of fairly uniform color was formed (Illustration 2c).

Illustration 2d shows what occurred when a zone was subjected to nonhomogeneous pressures; in this case the rock was slightly fractured; however, due to the depth at which it lay and to the long time that elapsed, the small fractures were filled by materials deposited by thermal waters so that the marble was still very compact.

and Antonio Canova.

In the United States, the exterior of the National Gallery of Art in Washington, D.C., is of Tennessee marble, and the Lincoln memorial contains marbles from Yule, Colorado; Alabama, and Georgia (the Lincoln statue itself).

Even the purest marble, such as that from Carrara, contains some accessory minerals and in many they form a considerable part of the mass. The commonest are quartz in small rounded grains, scales of colorless or pale yellow mica, dark, shiny flakes of graphite, iron oxides, and small crystals of pyrite.

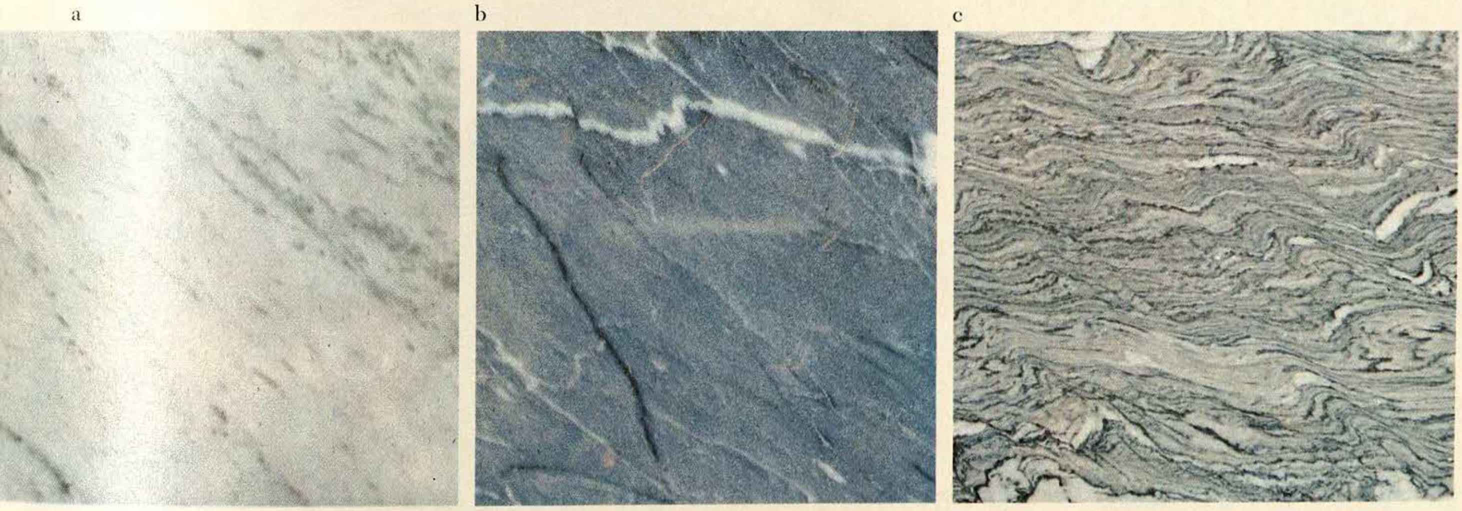
One type of marble, called breccia marble, often contains sharply angular fragments of other rocks with admixtures of various kinds bonded by a cement, usually calcareous but sometimes siliceous or even clayey. The diversified fragments impart a variety of color, giving marble a decorative and attractive appearance. The history of these rocks, always very complicated, is interesting to follow. They can be mined from caves or quarries; by careful study of the geology of the mountains where these caves or quarries are located, it is possible to reconstruct their history. Some of the most beautiful and well-known types of marble, including breccia marble, are illustrated.

3

THREE DEGREES OF ALTERATION—White marble from the Carrara quarries in Italy (Illustration 3a) is of homogeneous texture with slight amounts of veining, indicating minute percentages of impurities. Without these the marble would be of the highest quality, but such marble has almost completely disappeared from the Carrara quarries.

Another marble, also from the Carrara quarries, sky-gray bardiglio (Illustration 3b) is less homogeneous than white marble; it is streaked with whitish veins. When fractured, this marble emits a fetid odor. It has probably not been greatly altered.

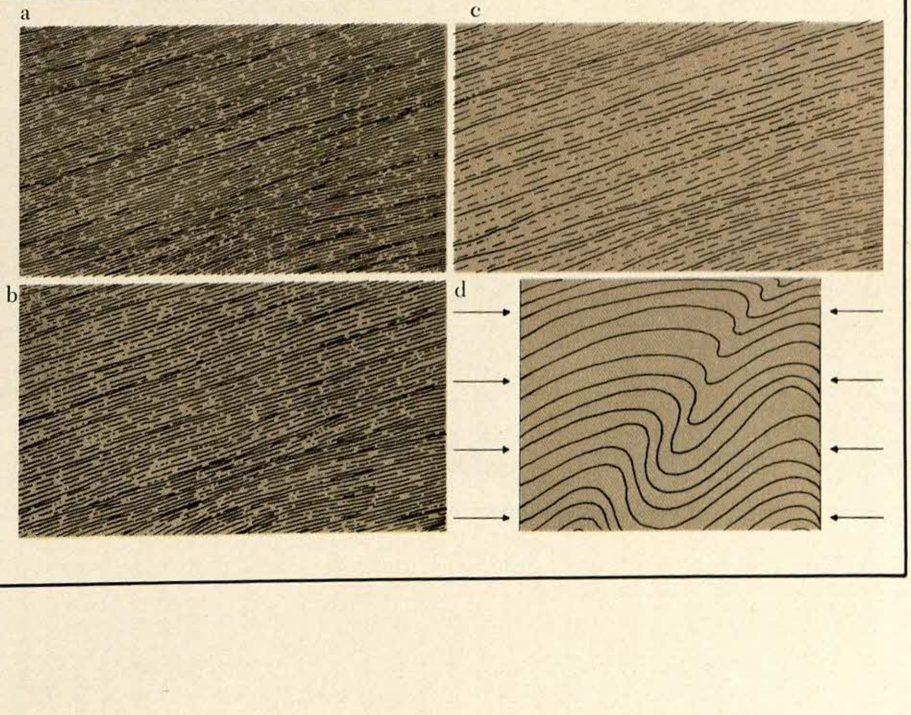
The green cipolin of Arni (Illustration 3c) has many fine folds, reflecting the great pressures and alterations to which the marble was subjected.

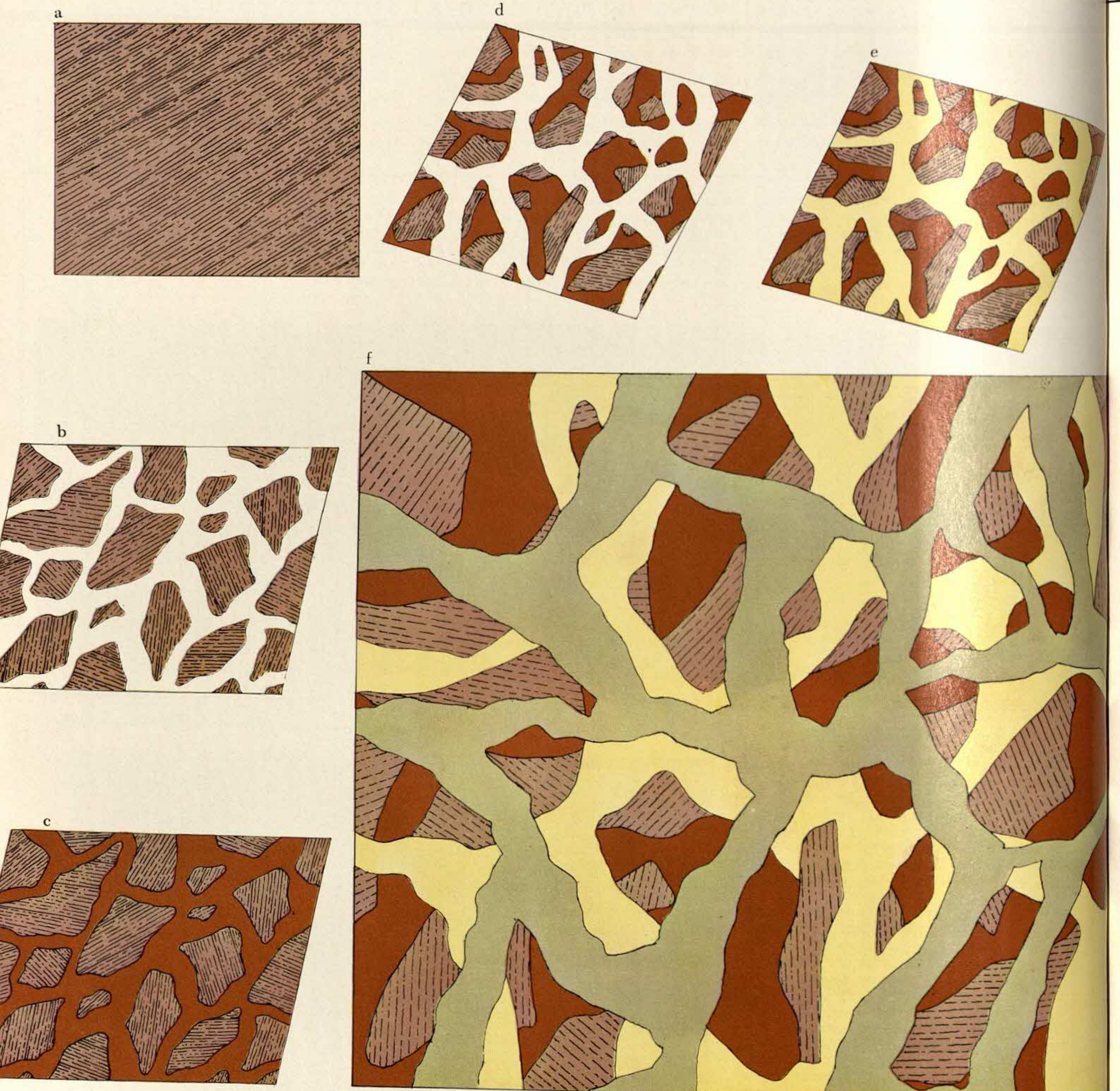


4

SLOW-ACTING FORCES—A marble such as the green cipolin of Arni offers clear indication of having undergone a long series of geological phenomena that profoundly altered the original rock. This sequence of illustrations shows the history of this stone and the reasons for its characteristic appearance.

In Illustration 4a, the marine sediment is barely deposited. After a certain number of years, pressures have brought on recrystallization, thus homogenizing the material (Illustration 4b). After a long period of time, the still uniform pressures have almost completely eliminated the veins in the marble (Illustration 4c). In Illustration 4d, the marble, subjected to strong lateral pressures, has been compressed along the planes of the veins, but this occurred so gradually that the layers of sediments were able to recrystallize, some very slowly. Those that recrystallized first are white because they were able to separate out the impurities that tended to concentrate in the more slowly crystallizing materials, causing the characteristic veins.




a
d
e
b
f
c

5

THE ORIGIN OF BRECCIATED MARBLE—The history of brecciated marble is complicated; this illustration gives a brief description.

The process begins with a marble that originated as shown in Illustration 2. When polished, such a compact mass (Illustration 5a) appears fairly homogeneous, as, for example, bardiglio. Traces of the sedimentation from which it originated or of the pressures and thrusts to which it was subjected are barely perceptible.

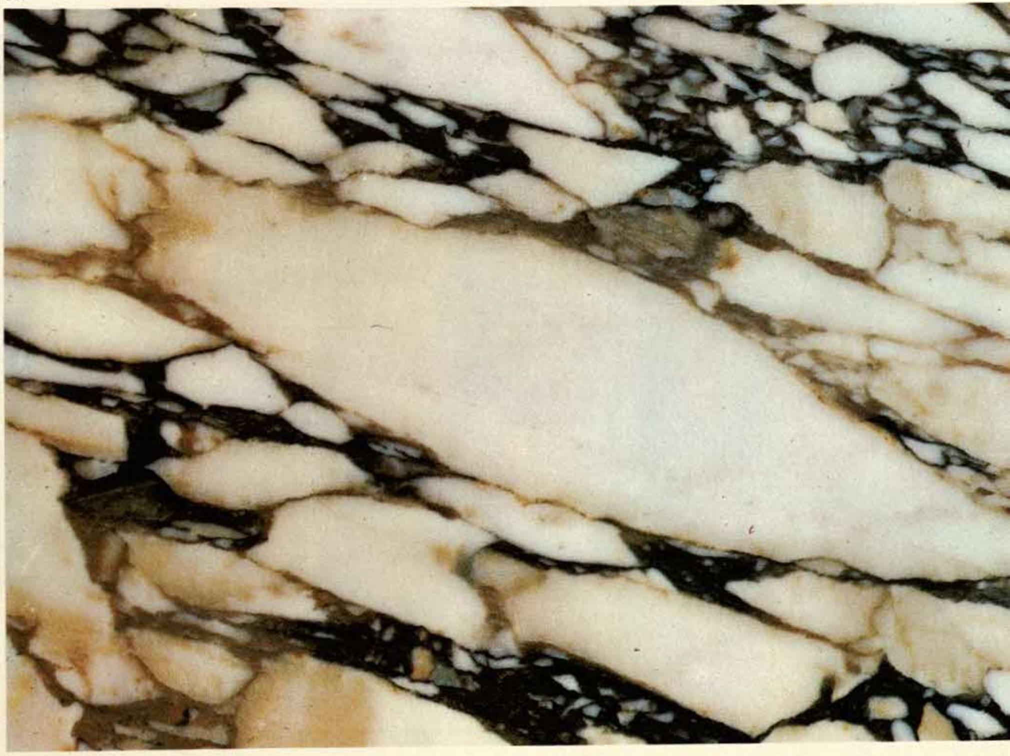
The marble undergoes strong pressures, either being crushed or pushed up to the surface and exposed to erosive agents of the open air which detach fragments and roll them down to the valleys, where they accumulate, forming what is called an incoherent breccia. This may be permeated with water that deposits materials to cement the broken fragments. Unless there are newly made fractures, a haphazard arrangement (Illustration 5b) is the result.

Illustration 5c shows a cross section of the breccia, which exhibits vivid coloration different from that of the original material.

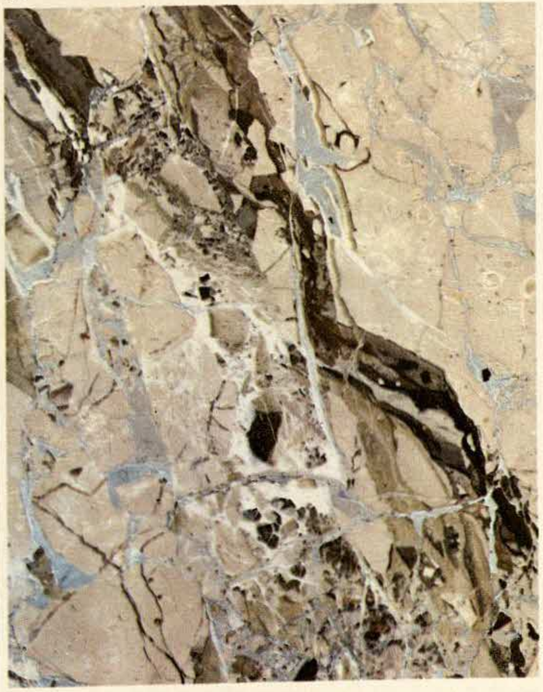
After cementation has occurred, the material is subjected to other forces that open new fractures traversing the blocks in haphazard fashion. A new, not yet bonded breccia appears (Illustration 5d).

Hydrothermic actions cause the cementation of this new breccia, which ultimately becomes compact (Illustration 5e). It may undergo still further fractures due to pressure or erosion, becoming more and more complicated in structure with new colors added, as in Illustration 5f. Sometimes a breccia accumulates in a place where fragments from different localities converge; it may consist of mixtures of rocks, some already broken up, of different origins and, therefore, of different structures, colors, and compositions. This produces more complex breccia of greater value and scientific interest. Similar phenomena, although quite rare, occur in siliceous as well as calcareous rocks.

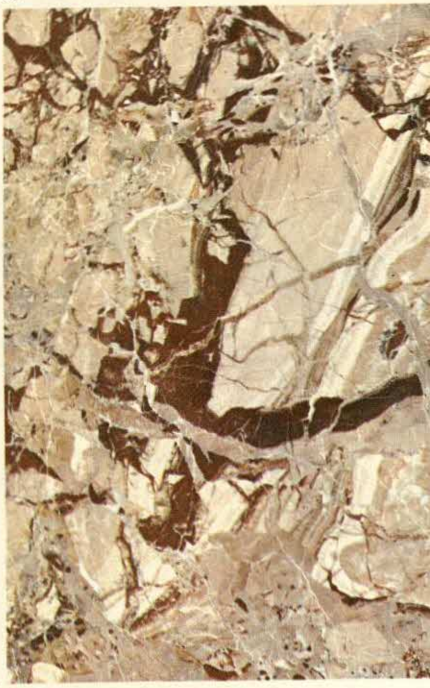
6a



6b



6c



BRECCIA—Brecciated marble is formed by the bonding of angular rock fragments. The specimen in Illustration 6a (see p. 53) is Skhyros, a beautiful stone extracted from the island of Scio in the archipelago of southern Sporades in Greece. This breccia results from cementation of a fractured marble by a calcareous material differing in color from the marble itself.

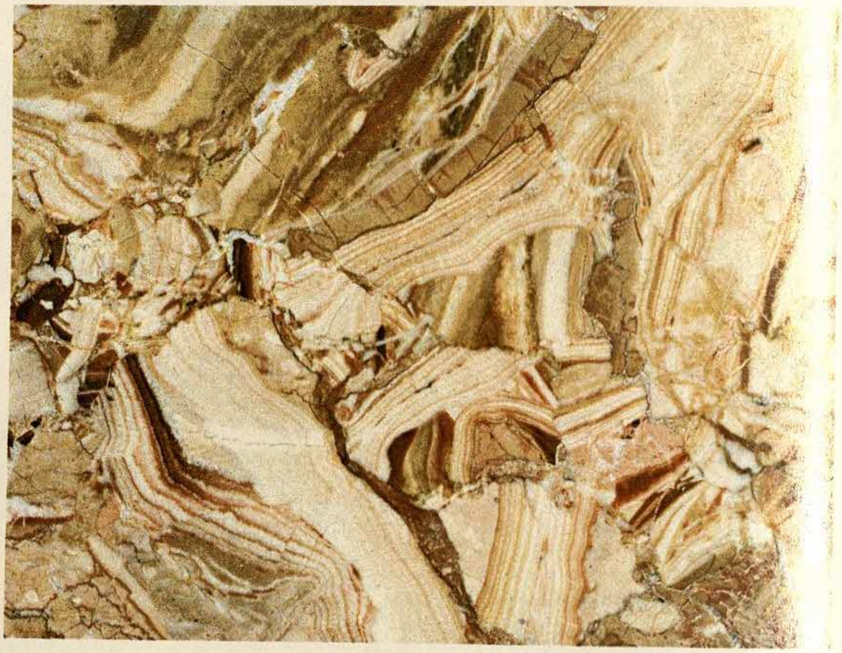
Dark Aurora (Illustration 6b) is a brecciated marble from the Apuanian Alps that apparently underwent two successive brecciations. The first was with dark material; the new rock was again shattered and the fragments were recemented by bluish materials. A mosaic breccia of this type, because of its beautiful colors, is quite valuable.

Illustration 6c is Aurora, another breccia which, like dark Aurora, underwent at least two fracturations and was cemented with at least two different types of materials.

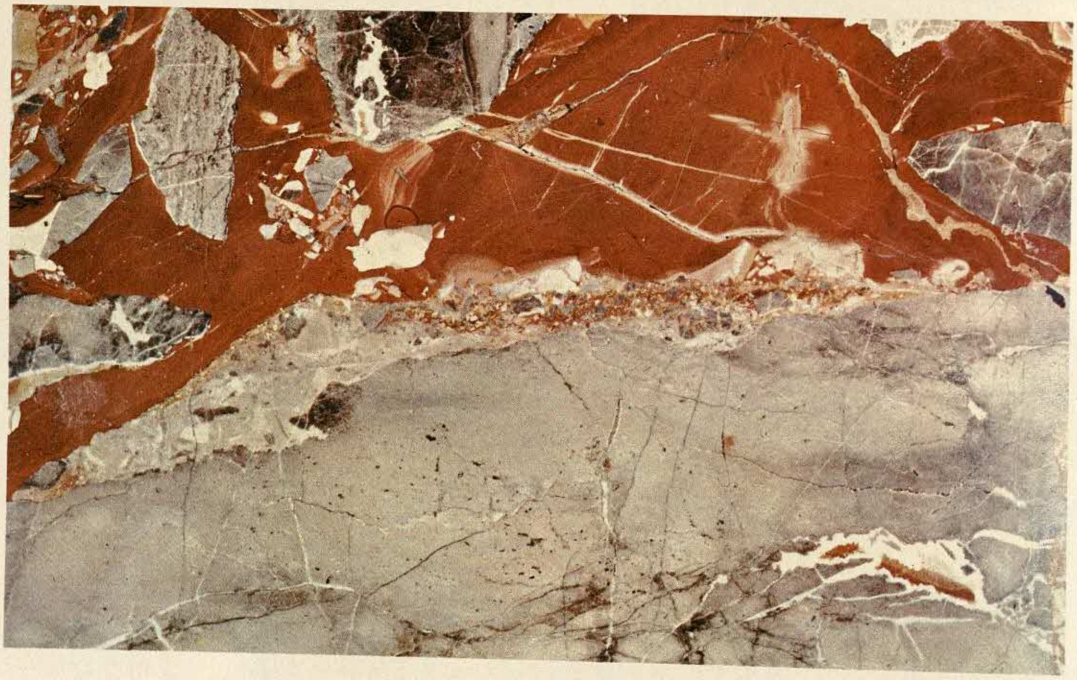
Illustration 6d shows libeccio, found in the vicinity of Messina in Sicily and also near Tripoli. This breccia is of a very complicated type; it is composed of fragments of marble similar to certain onyxes.

The specimen in Illustration 6e is still another type of breccia in which at least two types of initial materials have accumulated. This, together with the rose tint of the cementing material, makes the mosaic quite valuable.

6d



6e



OBSERVATION OF MINERALS

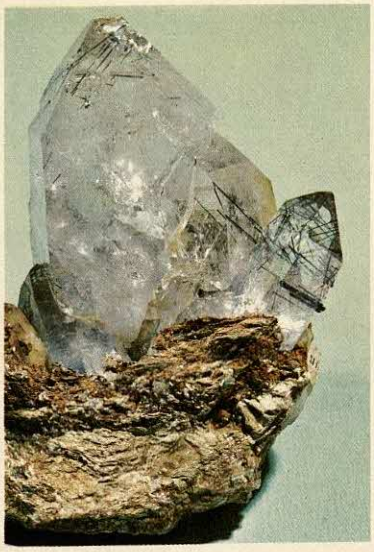
colors, associations, refractive indices

Mineral specimens can be collected in two different ways: by searching for them in the rocks in which they appear, or by buying them from a dealer. Searching for specimens has many advantages; for example, it is quite likely that in the course of an expedition many specimens of a particular mineral may be found. Some of these may be superior to others, but all can be collected and put to different uses. The most beautiful may be exhibited; the others may be used in experiments, for analysis, and for trading with other collectors. Moreover, collecting minerals by searching for them is inexpensive; about the only cost is that of making the trip. Some regions are noted for the variety of their minerals.

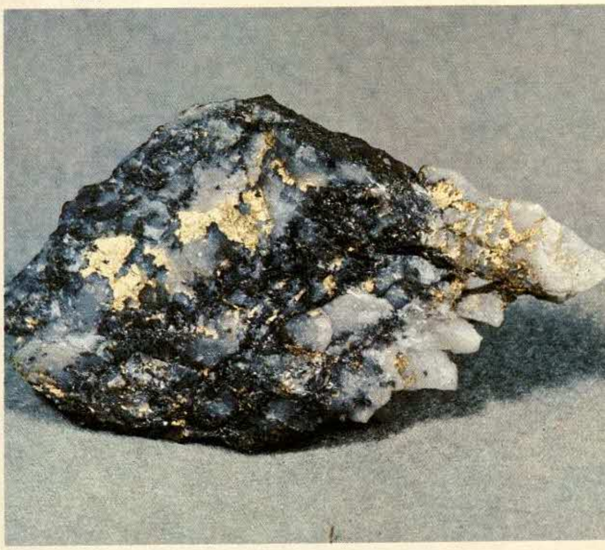
However, when a specimen of a specific type is desired, a dealer may be able to provide it immediately. A dealer is in a position to provide the best specimen of each kind as well as certain specimens that are difficult to find.

CRYSTAL ASSOCIATIONS—The mineral collector is soon faced with the need to diversify the collection quite extensively. The quartz family is already extensive even if only color varieties are considered, but it becomes even more extensive if crystal associations are taken into account. Associations always add to the interest of a specimen, as illustrated by these examples of quartz crystals (Illustration 2a) permeated by thin crystals of rutile, or a quartz crystal (Illustration 2b) associated with intrusions of gold.

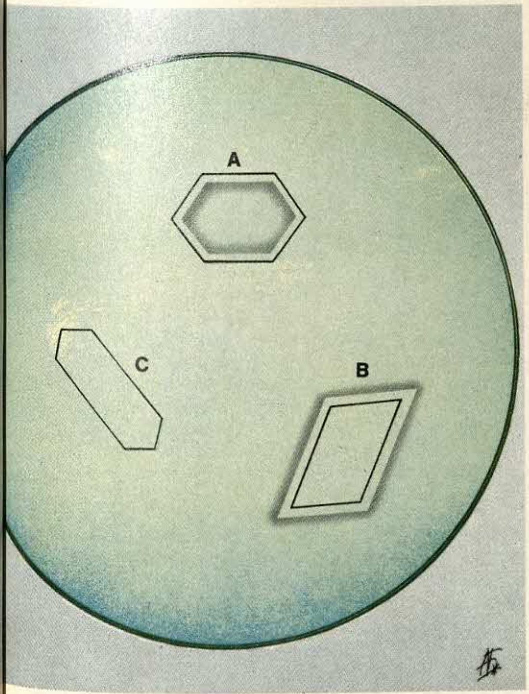
2a



2b



1



DETERMINING THE REFRACTIVE INDEX—The refractive index of a crystal is a very important property, varying from case to case. A crystal of quartz can be identified by its properties of color and habit; recognition in such a case is immediate, and once a crystal is recognized, its refractive index can be obtained from a table. In other cases, however, if the crystal is small or not characterized by any particular color or other property, it might be identified by measuring the index.

The measurement of the refractive index is based on a relatively simple principle and is carried out on a small fragment of the crystal. A fragment of the order of 0.1 mm (about 0.004 in.) appears quite large under a good microscope; however, a fragment about 1 mm (about 0.04 in.) is necessary if a good magnifying glass is used. Only transparent crystals or fragments of crystals can be measured in this way.

The fragment is immersed in a basin, illuminated from below and containing a liquid with a known refractive index. If the refractive index of the liquid differs from that of the crystal, a bright halo appears to surround the crystal, as indicated in the illustration; if the two indices are identical, the halo disappears.

In **A** the crystal appears, when illuminated from below, as if the microscope were not perfectly focused on the plane of the object; a slight blur or halo seems to define lines parallel to the actual outline of the crystal and inside that outline. In this case, the refractive index is higher than that of the liquid.

In **B** the blurred lines appear outside the crystal; in this case, the refractive index of the crystal is lower than that of the liquid.

Finally, in **C** no blurred lines appear; in this case the refractive index of the crystal is the same as that of the liquid.

The blurred lines that appear when the refractive index of the crystal differs from that of the liquid are known as Becke's lines (named for the Austrian mineralogist Friedrich Becke), and this method of determining the refractive index is called the Becke test.

The delicate part of the test consists of preparing the liquid with a known refractive index. The normal procedure is to start with a liquid having a low refractive index and then to add another liquid with a higher index until Becke's line disappears. Part of the liquid is then removed as a sample, and the refractive index of this sample is determined by using a refractometer. If no refractometer is available, however, another method is possible: The crystal is placed in a bath consisting of 100 drops of liquid petrolatum (which is sold with a statement of its precise refractive index, usually about 1.47); then, while continuing to observe the crystal, drops of another liquid with a higher and precisely known index—such as essences of various perfumes, juniper, clove, or cinnamon—are added, until Becke's line disappears. All these drops—those of the petrolatum and those of the essence—must be added with a device such as a chromatographic syringe or a micropipette, that indicates the precise amount of liquid as it is added. The refractive index of the mixture can then be calculated from the weighted average of the refractive indices of the components. Very high refractive indices can be determined by using liquids such as methylene iodide, which has a refractive index of 1.73.

Many approaches are possible to the observation of minerals. Those discussed here are relatively easy, require little equipment, and serve the purpose of classifying specimens and evaluating them by comparison with others already known.

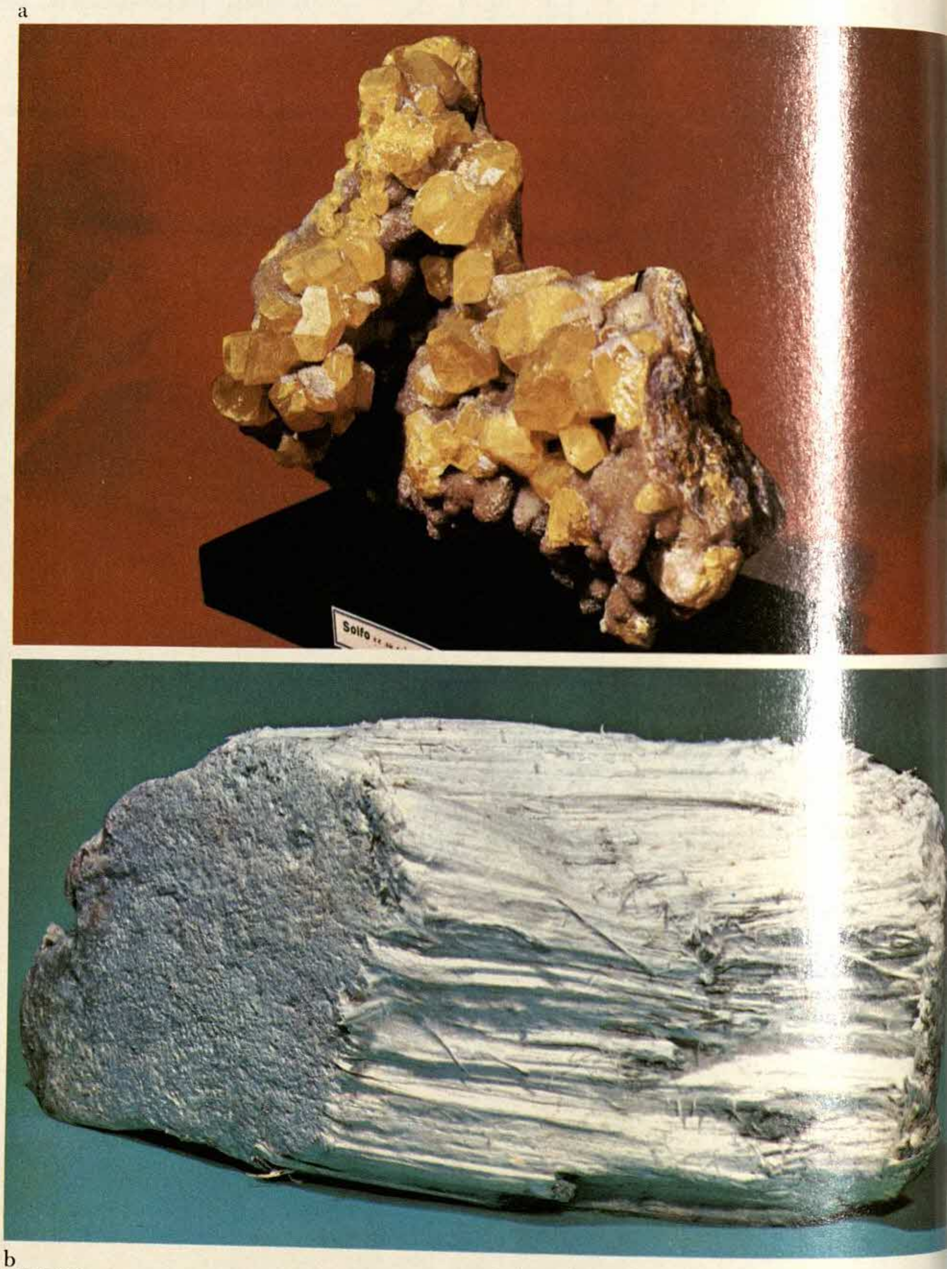
THE PURPOSE OF OBSERVATION

Apart from the observations described here, professional students of mineralogy most frequently devote themselves to the analysis of crystal systems—based on the angles between the faces of the crystals, and the atomic structure of the crystals—through the use of x-ray photography.

The mineral collector always tries to obtain perfect crystals, displaying their own habits of growth. This is possible only in certain cases; in the United States, for example, it is impossible to find emerald crystals with the characteristics of transparency and color peculiar to the emeralds used for gems. However, it is possible to find in North Carolina specimens with inferior color that are, mineralogically, the same substance. The estimate of the mineralogical value of such a specimen will thus be affected by observing analogous characteristics of other specimens exhibited in museums or found in other collections. One important factor, then, is the form of the mineral: whether the specimen has been made smooth in a placer-type deposit, whether the crystal developed in a geode or in a druse, or whether it was embedded in a matrix of rock that prevented its free development.

Among professional mineralogists, one of the most important observations is that of the refractive index, especially in the identification of doubtful species. Considerable determination but very little equipment is needed; therefore, this method of identification is quite suitable for an amateur. Moreover, it is interesting to observe how the crystal was formed and with which rock it is associated, because these factors help ascertain the origin and history of the mineral. At the opposite extreme, if the mineral under observation is a precious gem cut as a jewel, it will have little mineralogical interest because it is impossible to establish the remote relationship between the mineral and the rock environment in which it was formed.

3



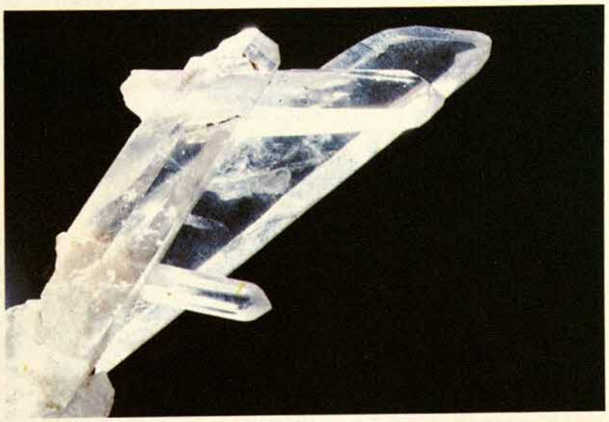
OBSERVING COLOR—Some of the observations discussed here involve a study of crystals and minerals in order to know their properties through direct examination of the specimens rather than through reading about them. Nevertheless, inasmuch as these observations can be of use in searching for minerals, they have a practical purpose as well. Once the color of a specimen is observed, it is remembered in all its subtle shadings and can, therefore, facilitate the search for a given mineral.

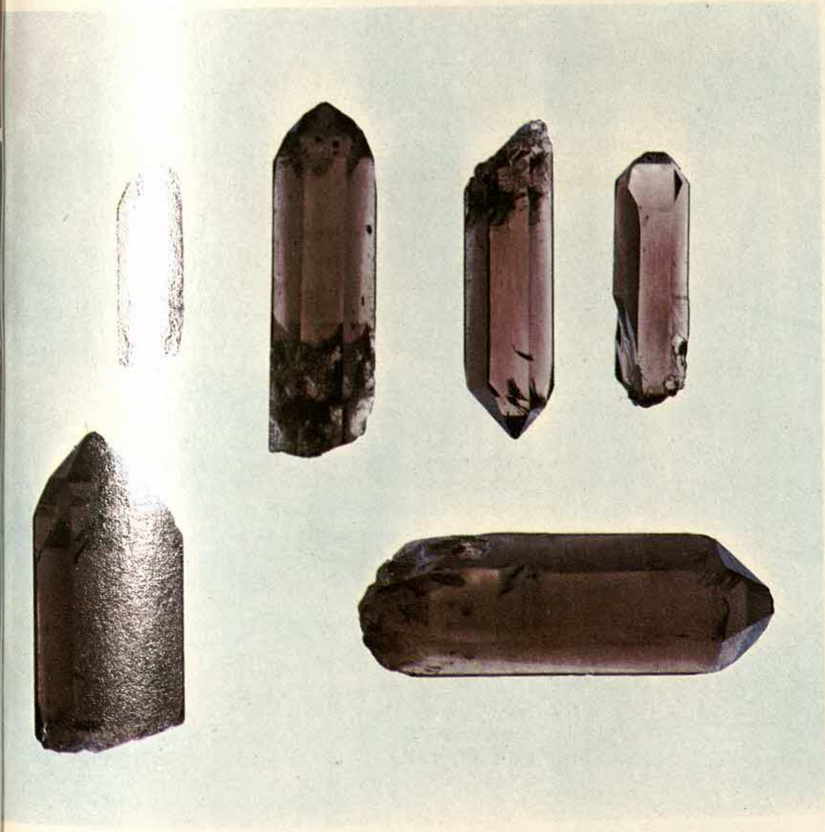
The first precaution that must be taken is to observe the color when the specimen is illuminated by the most natural light possible, preferably daylight. Experts insist on the best light, and inasmuch as the sunlight changes throughout the day, they always try to examine specimens at the same hour and under the same atmospheric conditions. Those who examine diamonds at Amsterdam, the principal center of the trade in jewels and precious gems, do not make appraisals after 11:00 A.M. because the change in the quality of the sunlight after that hour diminishes their ability to distinguish the more subtle shades of the stones. Although an amateur certainly does not need to be as exacting as this, he should if possible avoid an environment that depends on artificial illumination.

Observation of color is carried out at two levels; the first of these is merely the identification of the mineral's color. This series of photographs shows some minerals with characteristic colors. Even a beginner should know, for example, that sulfur (3a) is yellow, asbestos (3b) is light ash gray, and lapis lazuli (3c) is blue. But these are superficial observations; such approximate information, which

c

d





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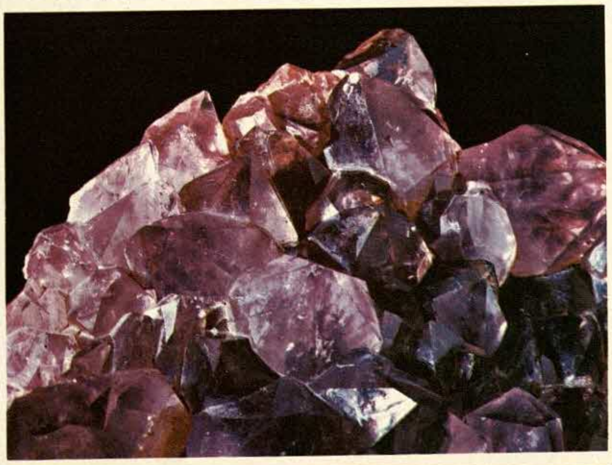
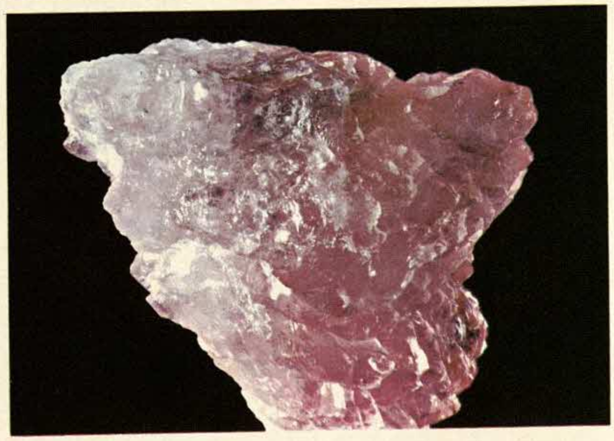


g



can be obtained from a visit to a museum, only serves as a foundation for more detailed studies. Knowledge of the color of minerals must be extended to the ability to recognize the nature and value of the various shades, as exemplified by those of quartz. Very pure crystals of quartz (3d), known as rock crystal, are as transparent as water; but the appearance of quartz is changed if it contains even a few parts per million of impurities. One such specimen is known as smoky quartz (3e). Many different kinds of smoky quartz exist, some tending toward a yellow color, some perfectly gray, and some (3f) with a violet color. The latter, known as amethyst quartz, may have many variations in the intensity of the color. A beautiful variety of quartz is found in various shades of pink and is known as rose quartz (3g). It must be remembered that these are only some of the colors found among quartzes and that many intermediate shades appear.

In observing the colors of quartz or any other mineral, origins and attributes of the coloration are significant. An amethyst crystal, for example, tends to be colored more intensely toward the point of the crystal than toward its base because the crystal was progressively formed from a liquid that contained impurities and that was gradually depositing its quartz content. Thus the impurities became gradually more concentrated at the very tip.

The origin of a color is not always easy to discover. Sometimes it is caused by the presence of impurities of a well-defined chemical nature, but it may also be caused by imperfections in the crystal that are difficult to identify.

The true color of the surfaces of minerals that have metallic luster (notably bornite) may be camouflaged by tarnish, an extremely thin film of alteration product.

CHARACTERISTICS OF MINERALS

a guide for collectors

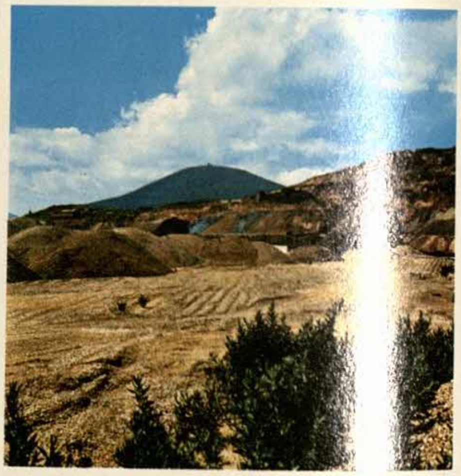
The Earth, like meteorites and other planetary bodies, is a great ball of minerals. Not only do minerals largely determine man's physical environment, but they also provide raw materials and energy.

Generally minerals are inorganic, naturally formed substances, having the following characteristics: natural occurrence, homogeneity, precise chemical composition or ranges in composition, regular internal structure, and inorganic nature. Mineralogy, the study of minerals, includes discovery, identification, description, and classification of the different mineral species, study of their geological occurrences, explanation of their origins, nature and crystal properties, and consideration of their practical uses.

Many observations regarding crystal properties can be made visually or with simple instruments. The following experiments serve as a guide for collecting and identifying minerals.

1a

1b



1c

LOOKING FOR SPECIMENS—Most rocks in which crystals are likely to be found are covered by soil; if exposed, they may have been ruined by atmospheric agents that have destroyed the crystalline structure and weathered the rock.

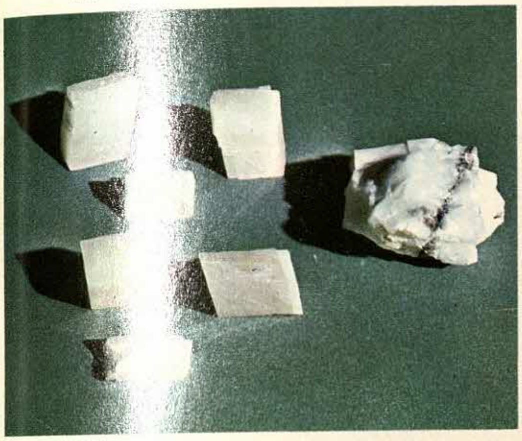
Rock quarries (Illustration 1a) are among the best places to look for specimens. The entire surface of a quarry is a possible source. Generally, large crystals are not homogeneous and can be discarded.

Mine dumps (Illustration 1b) are also a good source for specimens. The dumped material generally consists of small pieces of rock that have broken at the very points where there is a crystal of more than average size. Such crystals generally represent points of weakness and are often found along the lines of fracture.

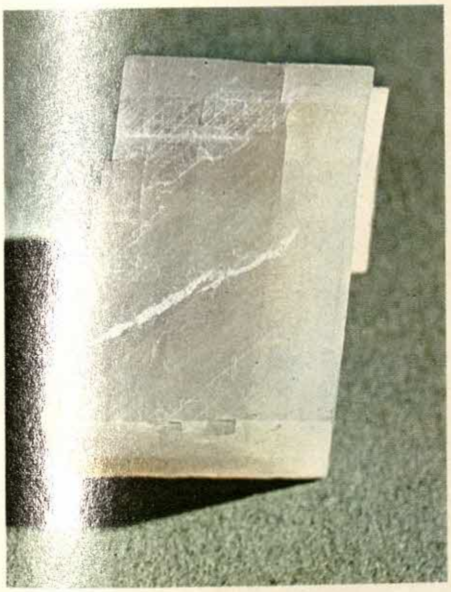
Another rich source of minerals is the glacial moraine (Illustration 1c). In general the crystals found here have been detached from a rock face in the comparatively recent past and are, therefore, less heavily weathered than those from other sources. The small stream that issues from the foot of the glacier is also a likely place for crystals. The torrent picks up stones from the moraine and carries them down, rounding them off as they are dragged along. Possibilities of finding intact specimens decrease in proportion to the distance from the foot of the glacier.

Other places in which rock collectors may find desirable specimens of colorful and interestingly shaped rocks are road cuts, building excavations, beaches, and stream beds.

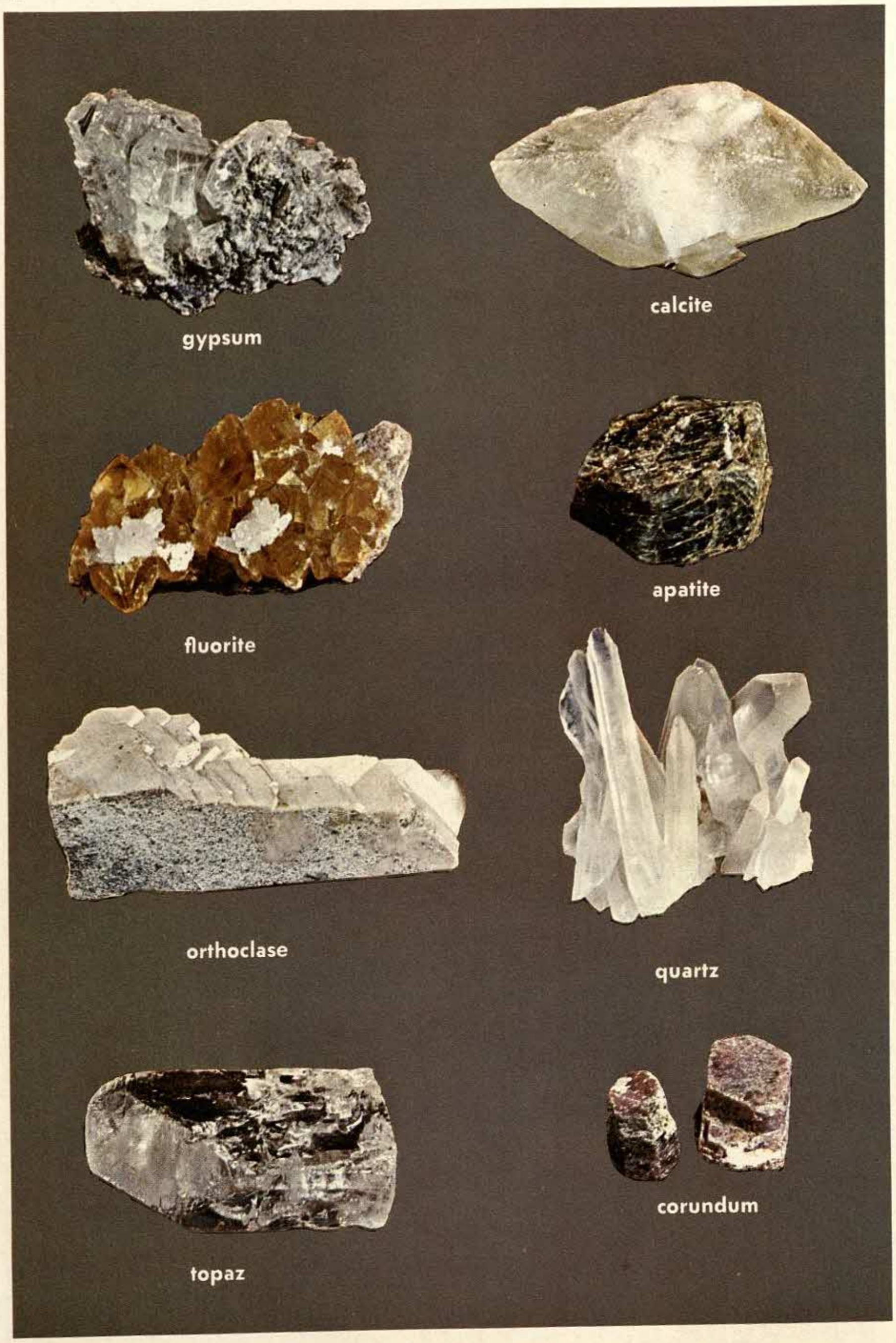
2a



2b



2c



IDENTIFICATION OF CRYSTALS—Accurate identification of minerals is often difficult because most samples exhibit appreciable ranges in composition. Moreover, most minerals are intermixed with one or more others. Identification of a sample by comparison with one in a mineralogical museum is rarely useful because museum specimens are often chosen for their exceptional beauty and purity, and are quite unlike those generally found in the field. Most calcite crystals in rock, for example, are impure and whitish in color, quite unlike pure Iceland spar, which is as transparent as optical glass. If the calcite is found enclosed in rock rather than in a cavity, it will not have the characteristic rhomboid shape.

The following elementary field methods are valuable in identifying specimens. The first examination is made when the specimen is separated by hammer or other tool from the parent rock. The manner of cleavage is an aid in identification. If cleavage fragments in the form of rhombohedrons are produced, the mineral is usually calcite. Quartz, which in large masses often has a whitish appearance like calcite, fragments into a conchoidal fracture like glass, providing it has not already been fractured and weakened by pressure in the parent rock. Illustration 2a shows white and impure calcite cleft into small rhombohedral fragments.

Another identifying property of minerals is hardness. Calcite and quartz, for example, have very different hardnesses. Quartz can scratch calcite (Illustration 2b) and thus help identify the latter.

Illustration 2c shows a group of crystals useful in identification of mineral specimens. On the Mohs' hardness scale, the mineral gypsum has been given a hardness of 2, calcite 3, fluorite 4, apatite 5, orthoclase 6, quartz 7, topaz 8, and corundum 9.

Crystals used as standards of comparison do not have to be pure. Impurities generally increase hardness, but not enough to invalidate comparison testing. Each crystal needs a point or cutting edge, usually produced by a careful blow from hammer and chisel. Small crystals must be handled with great care.

In testing for hardness, the cutting edge of a crystal may be lost if it is used against a harder crystal. If a piece of quartz is used to scratch another piece of quartz, the cutting edge may be blunted; if the unknown mineral is calcite, however, it will be scratched and the testing sample will not be blunted.

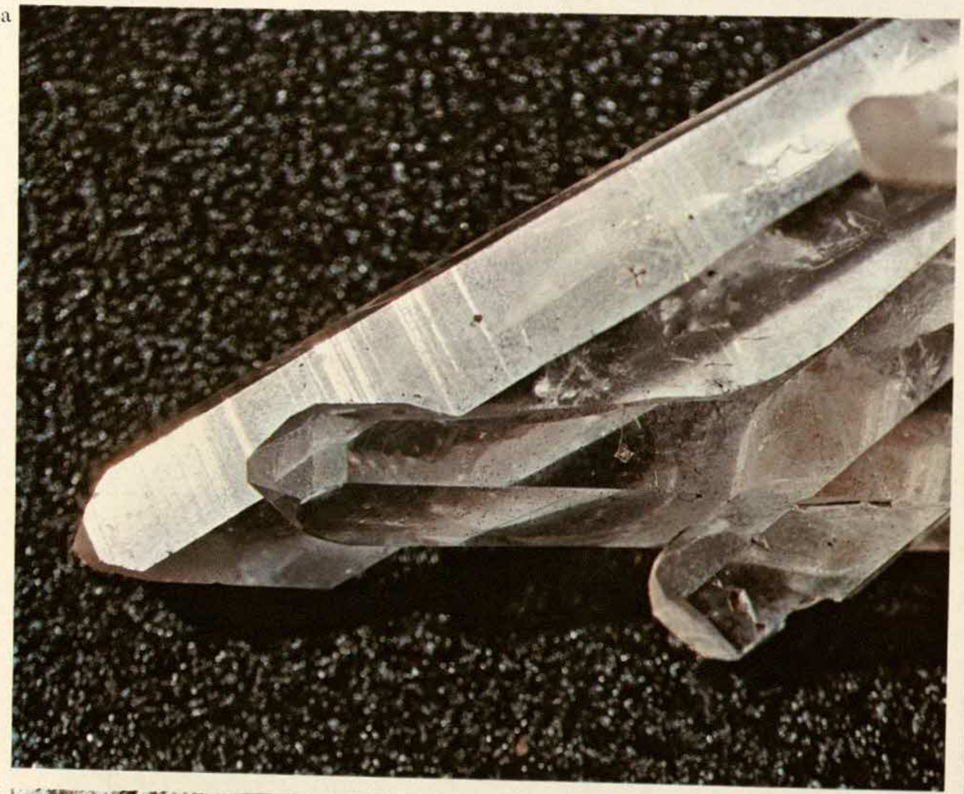
PERFECTION OF FORM—A pure and well-formed crystal appears to have plane faces, although these are not really planes in the optical sense. Actually, a crystal grows through the presence of certain growth-favoring defects in its structure. Consequently, each of the faces contains terraces. These terraces have characteristic forms for each mineral or class of minerals that are useful for identification purposes.

Illustration 3a shows the faces of a fairly perfect quartz crystal. The planes are striated perpendicular to the axis of the crystal; the striations are curved in section and almost cylindrical in form. In a chemical sense, this type of striation is independent of the degree of perfection of the crystal; the same striations are found on milky-white or white crystals.

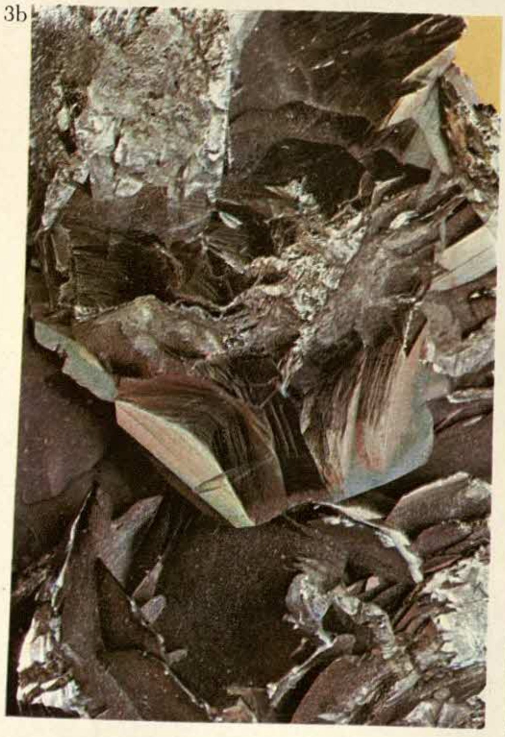
Another characteristic striation is that found on hematite (Illustration 3b). Although the photograph has been greatly enlarged, the striations are easily visible to the unaided eye. For examining very small crystals, a lens capable of enlarging from five to ten times is helpful.

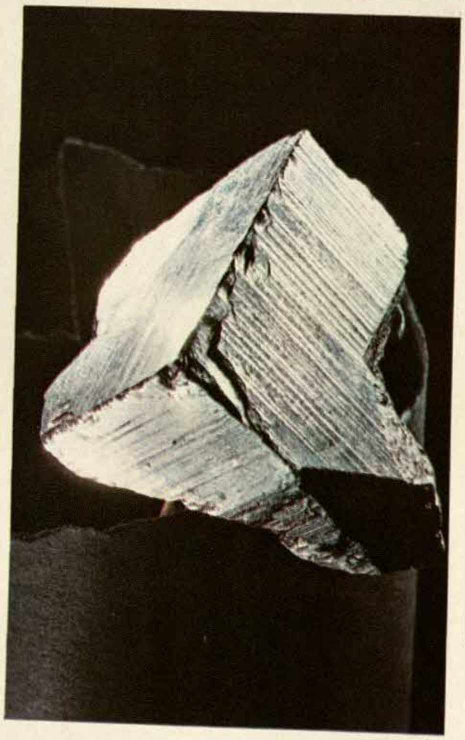
The direction of the striations on each face of cubic pyrite (Illustration 3c) is always parallel to an edge of the face and perpendicular to the striations of adjacent faces.

3a



3b

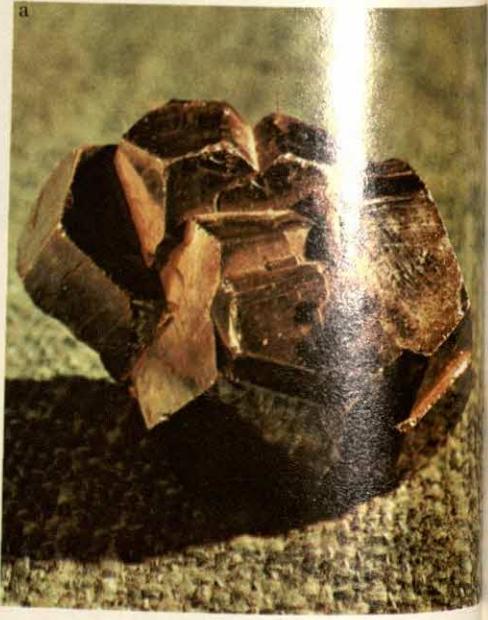




3c

ADVANCED OBSERVATIONS—In making a mineral collection, it is desirable to obtain specimens of all the forms and crystal associations in which a particular mineral can be found. Illustration 4a shows quartz associated with a form of limestone; in Illustration 4b, quartz is associated with an igneous rock.

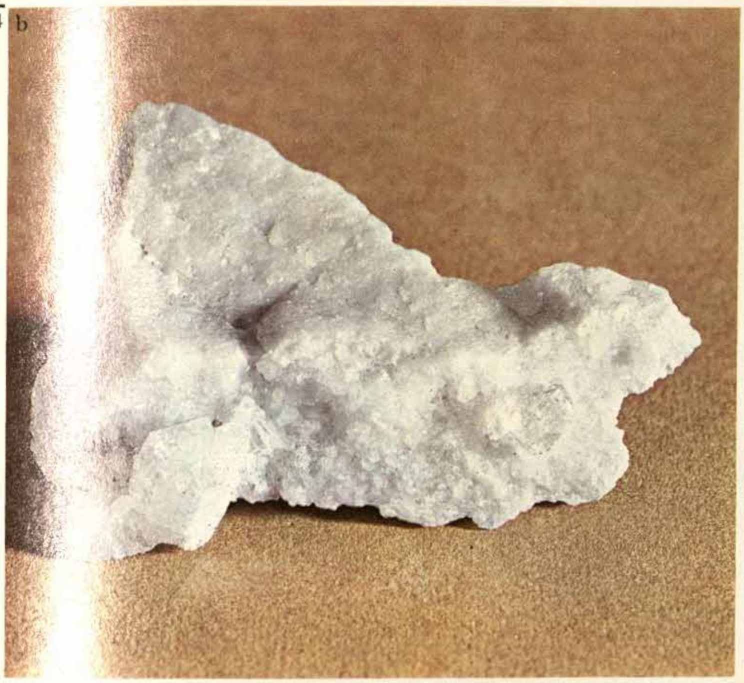
a



Twinning is another characteristic crystal association. A complete list of the forms of twinning can generally be found in mineralogy textbooks.

Another identifying feature is the association of different types of crystals, particularly

4 b



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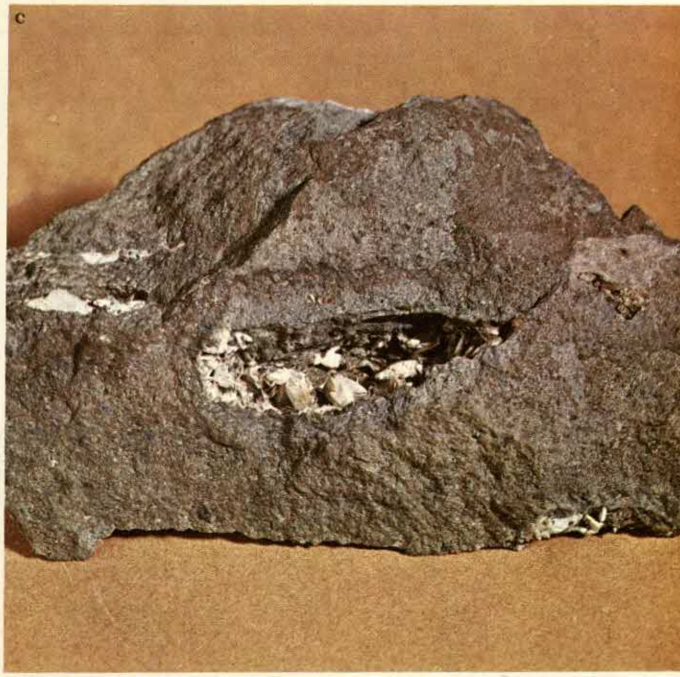

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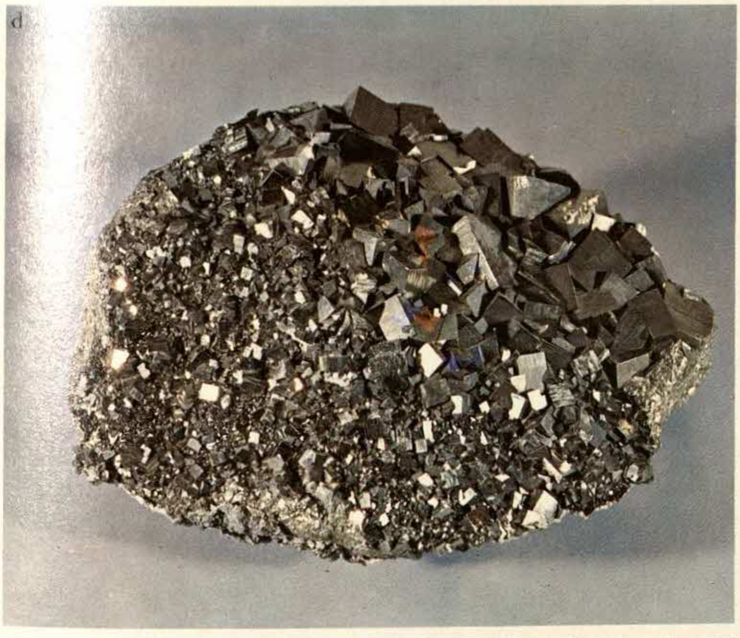
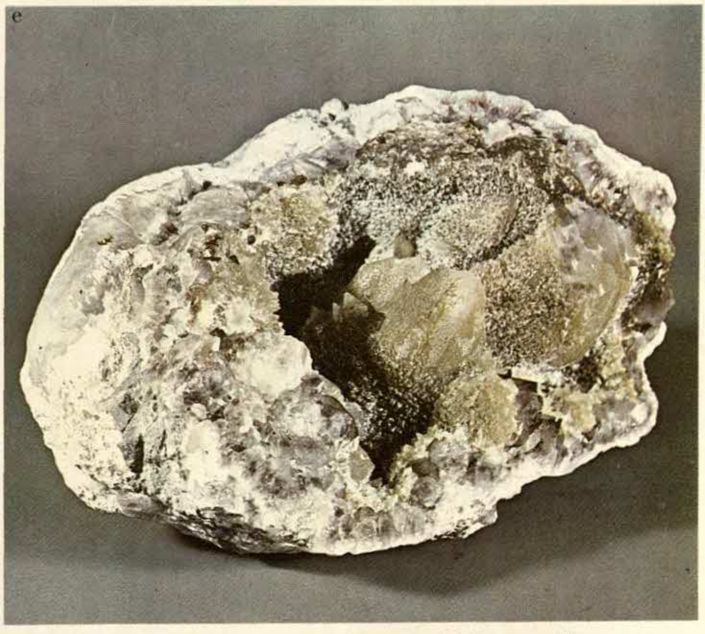


e



when the genetic history determining the association is known. For example, Illustration 4c shows minute calcite crystals formed in a geode of amethyst quartz.

Two different crystalline forms of the same chemical compound may be found in the same specimen—for example, calcite and aragonite. Illustrations 4d and 4e show what appear to be two very different species. Actually, however, cubic pyrite (Illustration 3c) and pentagonal dodecahedron pyrite (Illustration 4e) are different forms of the same compound. Substances of the same chemical composition but of different structure are *polymorphs*.

Twins and individuals of different crystal structure are often found in particular mines or regions; it is useful, therefore, to identify the place where each specimen is found.

THE ORIGIN OF MINERAL DEPOSITS

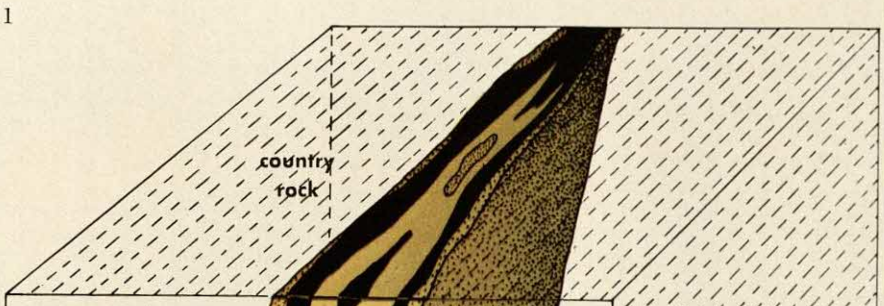
classification of the principal veins

A mark of an advanced technology is man's ability to exploit a great variety of mineral deposits from which he extracts elements that are useful for his industries. However, the extent of this variety makes it difficult to classify these deposits into a general scheme. Once the structure of a deposit is accurately known, it can be classified as either a typical deposit or one transitional between two different deposits. The study of its constitution is very important, because it indicates which methods and equipment will enable the material to be extracted in the most economical manner. Two identical deposits will never actually be found, although those that have been formed in analogous ways may be quite similar.

When studying a mineral deposit, the geologist must reconstruct the history of its formation by an examination of its structure, and thus arrive at a knowledge of its characteristics. Then he is able to predict the possible extent of the deposit from the nature of the formation in which it is located, and also suggest the direction in which mining operations should extend. Knowledge of the structure and history of a deposit often enables the geologist to predict the existence of similar deposits in other regions where similar geological conditions are known to have occurred.

This article explores the detailed structures of some characteristic mineral deposits, including various types of veins, deposits of chemical or organic origin, and salt domes. Each of these has unique characteristics and differs quite substan-

1



THE VEIN—An important type of plutonic deposit is the hydrothermal vein, formed by the passage of hot water of magmatic origin through fractures in the ground (magma emits large amounts of vapor during the last phase of cooling; in the incandescent condition these vapors remain dissolved in the mass of the magma). Hydrothermal waters can reach temperatures of several hundred degrees C and are, therefore, capable of maintaining in solution great quantities of minerals that are insoluble at normal temperatures. These waters may cool rather slowly as they rise toward the surface or diffuse toward other rock formations, and they will, therefore, deposit substances that are dissolved in them. Because of their prolonged presence in the area of origin, the waters will generally be almost saturated with dissolved substances, so that even a slight lowering of the temperature leads to an immediate deposition. This is the origin of a vein, but it may have a much more complex history.

The illustration is a detailed view of the various parts of a vein of a rather complex type; it is subdivided into various bodies, each of which consists of a different material. Only the light-colored part along the axis of the vein is of interest for mining. However, the surrounding parts must also be studied to understand the genesis of the mineralized formation of which the vein consists.

2

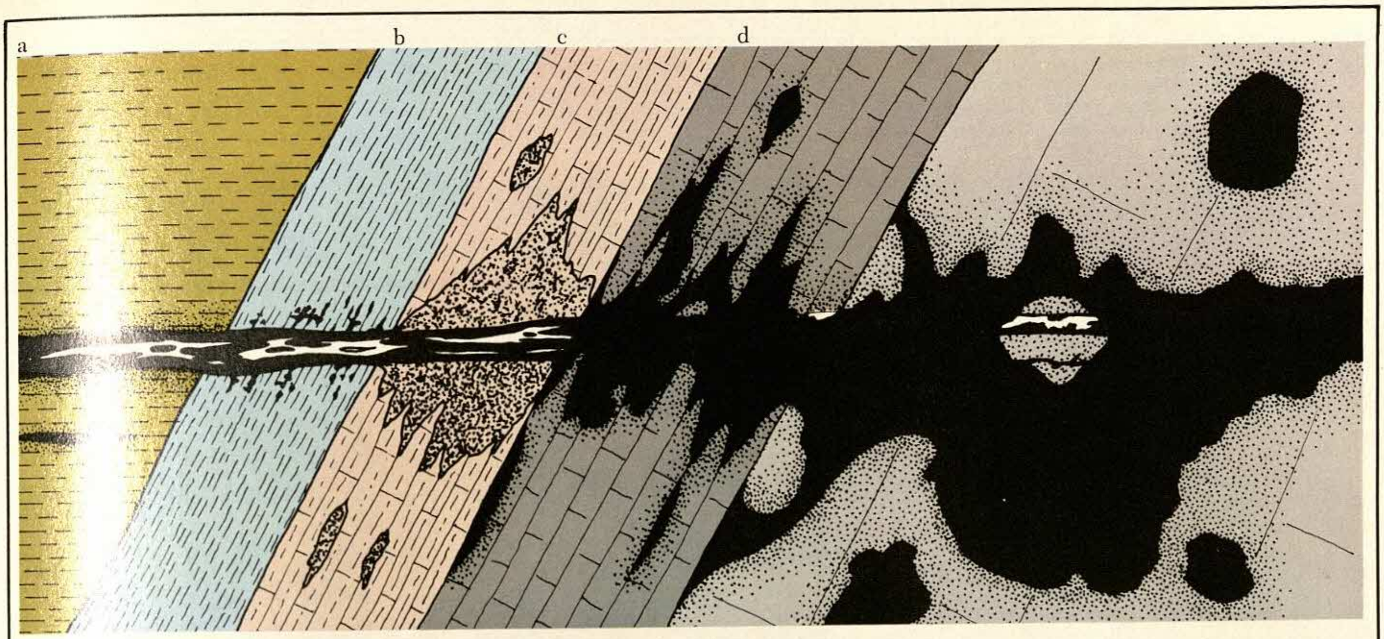
THE CLASSIFICATION OF VEINS—These illustrations show the principal types of veins and highlight their origins. When veins of one of these types are found in an area where similar veins have been productively exploited, the new veins are also likely to be productive and it can be presumed that the invisible part of the vein is also exploitable.

The massive vein (Illustration 2a) is the simplest type. Hydrothermal water has found its way into the fracture and progressively deposited the mineral throughout its volume, thus constructing the vein. The illustration shows the vein as if its mass were perfectly uniform. However, the vein was constructed by the progressive filling of the fracture in the rock; therefore, as the fracture opening was gradually reduced by deposition of the mineral, the circulation of the hydrothermal water must have become slower as its own deposits gradually closed the available passage, causing a variation in the rate of deposition. Small variations in the crystalline state caused by the variation in deposition rate are recognizable under the microscope.

The stratified vein (Illustration 2b) is characterized by layers of different minerals parallel to its length. Presumably the fracture in which the mineralization occurred became enlarged during the process of deposition, causing a variation in both the composition and the quantity of the flowing liquids. The opening of a rock fracture gives rise to conditions that can influence the quantity of the flow of hydrothermal waters, varying the thermodynamic conditions of the area in which the deposition is taking place and possibly leading to a change in the crystalline species of the deposits. Because these changes occur very suddenly, the vein consists of layers of completely different compositions.

The formation of a breccia vein (Illustration 2c) is somewhat more complex. The first stage occurs when hydrothermal waters pass through a fracture in rock and form either a massive vein or a slightly more intricate one. The vein resulting from the complete filling of the fracture becomes the seat of a fault; the vein is first fractured and then turned into a breccia during the slip, possibly accompanied by a widening of the cleft. Thus the hydrothermal waters can circulate once again, but with a different composition; eventually they fill all the free space in the breccia. The useful min-

3

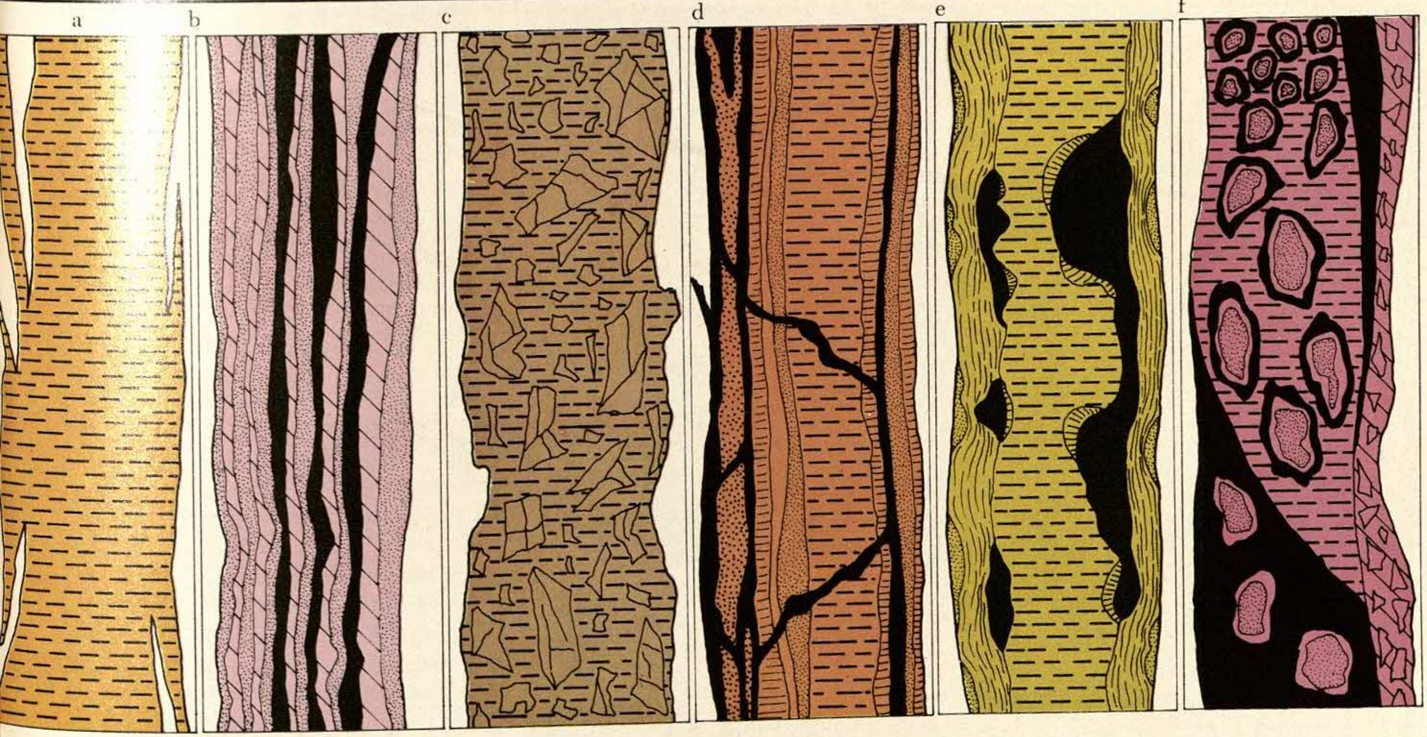


HYDROTHERMAL BODIES AND COUNTRY ROCKS—A hydrothermal body assumes the form of a vein in particularly hard rocks—for example, in intrusive or metamorphic rocks. However, it is possible generally to classify the forms it will assume when it passes through other types of rock.

In intrusive or metamorphic rocks, which are very compact and impermeable, the hydrothermal vein assumes a simple characteristic form (Illustration 3a). The impermeability of the rocks prevents the fluid from leaving the fracture, although inside the fracture it can circulate quite freely.

In a porous rock such as sandstone, a vein, even if formed inside a fracture, will always be accompanied by secondary bodies formed by the diffusion of water into the surrounding areas (Illustration 3b). Because sandstones are uniformly porous, the area affected by the passage of water is filled with mineralizations in which the useful mineral may be found in frequent but often minute masses.

In a compact but fractured rock—for example, stratified limestone—the vein will branch out along all possible planes of fracture (Illustration 3c). Both limestones and dolomites are very soluble in water, particularly hot water. The secondary veins may, therefore, be transformed into sacs. The phenomenon of substitution may occur on a large scale in an intensely fractured rock, leading to extensive mineralization (Illustration 3d).



eral may be either the first, which is in the form of inclusions, or the second, in which these fragments are imbedded.

Complex veins (Illustration 2d) may be formed if the mineralization takes place while the fracture gradually continues to widen; lateral fractures will also be formed, some of them connected with the principal fracture by a series of transverse fractures. The composition of the hydrothermal deposits will change every time the fracture widens or becomes amplified by new lateral or transverse fractures.

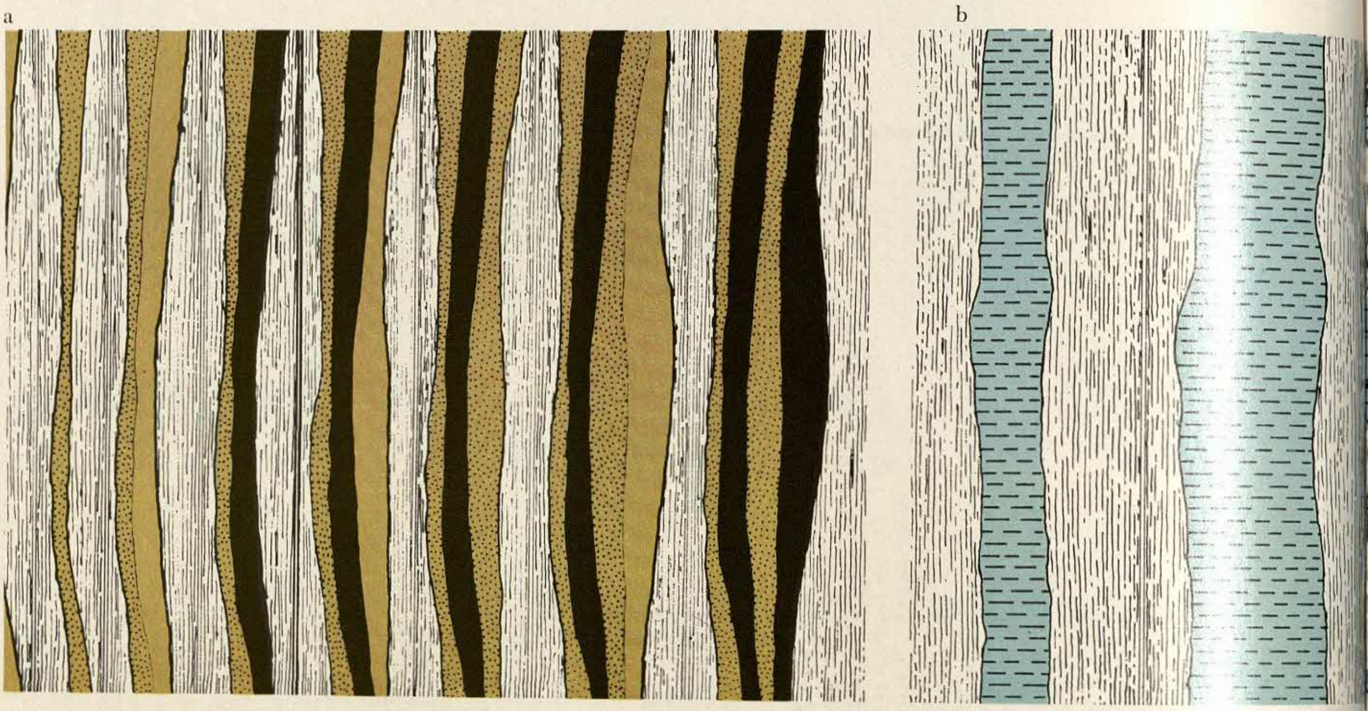
The symmetrically structured vein (Illustration 2e) is characterized by mineralizations of equal thickness at the same distance from the bed and the roof of the vein. The distribution of the mineral is also symmetrical over the width of the vein. Presumably the deposition occurred first along the walls and subsequently toward the center while there was a gradual change in the composition of the solute, but without any variation in the width of the original fracture due to the settlement of the rocks.

A vein with a spotted structure (Illustration 2f) is formed when the mineralization is subjected to slow processes of metamorphosis at the contact surfaces between the useful part, which constitutes the ore mineral, and the inclusions that form the gangue.

4

THE GENESIS OF VEINS—Here are illustrated the histories of the formation of the principal types of veins whose fundamental characteristics are described in Illustration 2. Illustration 4a shows the slow and progressive filling of a fracture that gradually widens as the hydrothermal deposition proceeds; this is accompanied by a gradual change in the composition of the substances dissolved in the water.

However, if the widening occurs suddenly and discontinuously rather than gradually, sud-



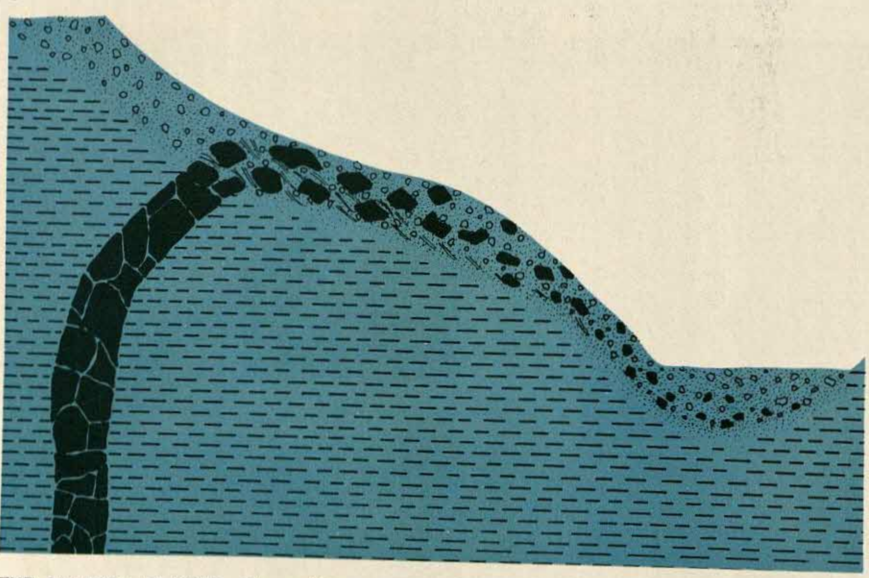
tially from the others in both form and structure. These differences make it possible to obtain useful information regarding both the best way to exploit the deposit and the reconstruction of the history of its formation.

The structure of each type of deposit reveals many details of its origin. For example, certain deposits may be formed around a plutonic formation, but even these deposits may have different characteristics according to the positions they occupy with respect to the parent formation.

Thus the study of mineral deposits lies between pure and applied research. The phenomena that led to the formation of the deposits are suitable objects of study, but a great deal of knowledge is required to arrive at useful conclusions for the exploitation of the deposits. The particular phenomena revealed during the work of excavation and exploitation are useful in furthering and completing theoretical knowledge in this field.

Many challenging problems remain to be explained, and many explanations already proposed in connection with the occurrences of minerals are working hypotheses rather than proved fact. Furthermore, mineral evolution is a dynamic process, as geologic environments undergo continual change in geologic time, and mineral assemblages tend to change with them.

5



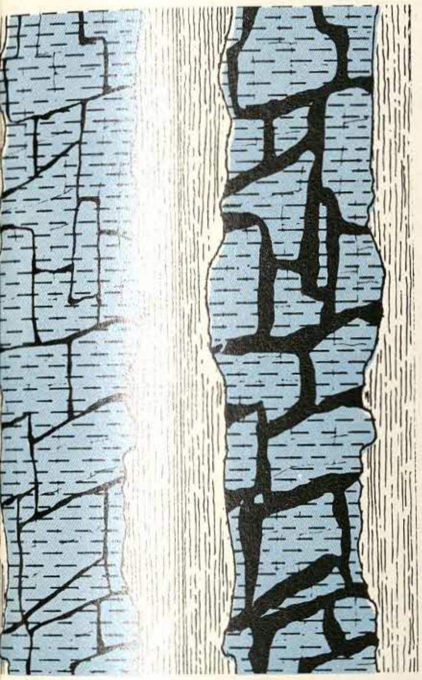
THE ALLUVIAL PLACER—The auriferous alluvial placer is a characteristic sedimentary deposit (other alluvial placers may also contain useful minerals—diamonds, for example), formed as a result of the destruction of another deposit. The original deposit probably would not have been exploitable, but its destruction caused a concentration of the useful mineral.

The illustration shows an auriferous vein embedded in a country rock that forms a hill. The vein consists of quartz; gold in its native state is in the form of small granules distributed between the quartz crystals. Erosion caused by atmospheric agents will gradually wear down the hillside and lead to the progressive breaking up of both the country rock and the vein itself. The gold particles will not remain attached to the quartz crystals; a loose mixture of the two components will be formed.

Water draining from the hillside will carry this mixture toward the bottom of the valley and the bed of the river to be found there. Because the quartz is lighter than the gold, it will be carried down faster; in time, the hillside will become covered with a layer of sand that is particularly rich in gold. This natural process is copied by gold-extracting mining techniques and, in former times, was copied by miners who laboriously separated, by hand, gold particles from water and sediment in riverbeds where the quartz particles are washed downstream more rapidly than the gold-bearing sands.

den change in composition occurs, explaining the outlines of the breccia fragments. Illustration 4b shows the history of such a vein.

Illustration 4c shows a vein that was wholly formed by deposition in a fracture that widened at a regular but discontinuous rate, leading to the formation of a zoned vein. Generally, this type of vein forms only in fractures so narrow that they may be considered as capillary fractures.



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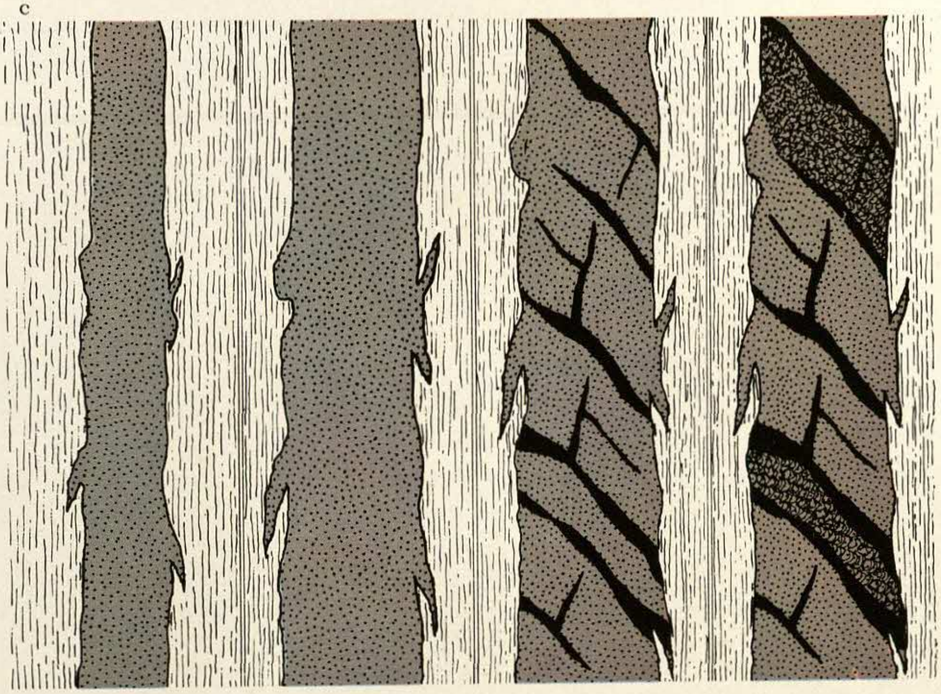

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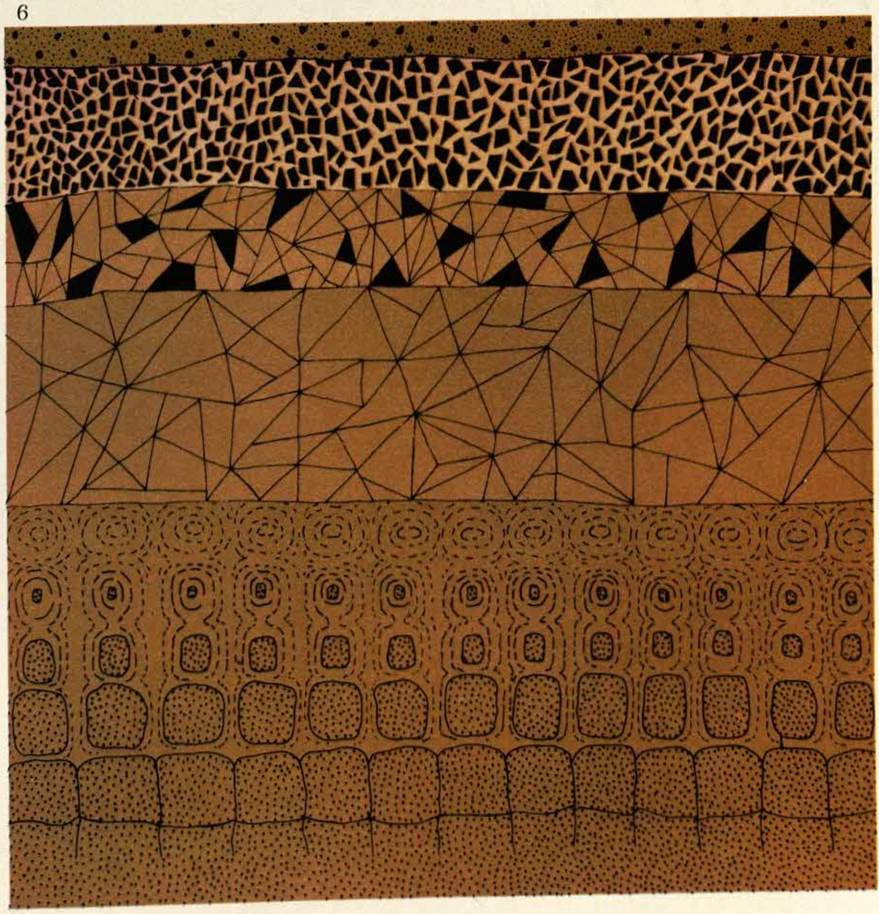


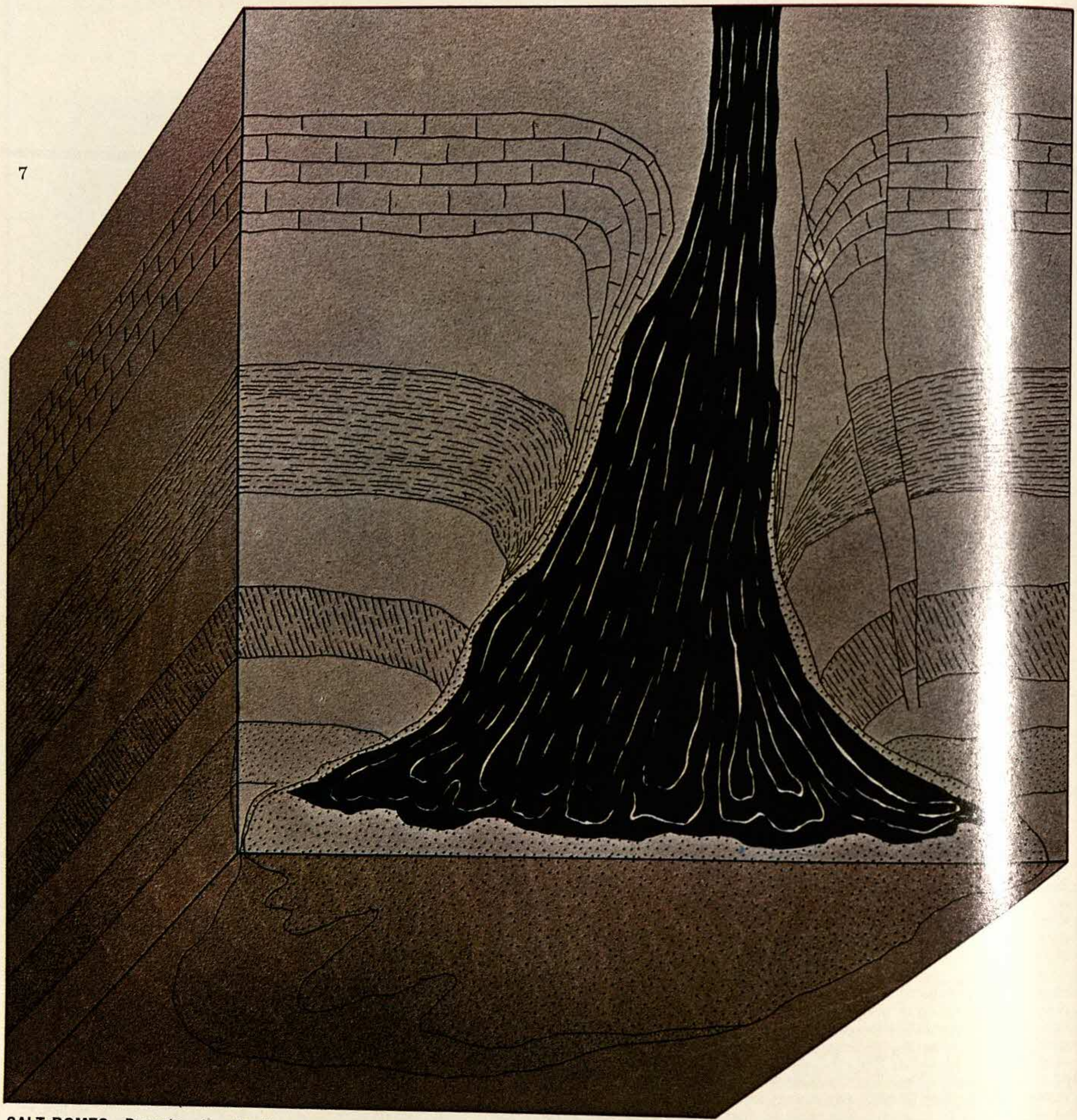
A DEPOSIT OF CHEMICAL ORIGIN—This illustration shows a typical deposit formed by the chemical transformation of rocks. This formation was caused by a mechanical crushing of the rock formation and the subsequent transformation of its crystalline components by the action of various agents, including water rich in dissolved carbon dioxide. Rock weathered in this manner is reduced to a mixture of soil consisting of silica, alumina, iron oxides, and certain other elements. Sometimes a concentration of one of these elements occurs, as in the case of the bauxite deposit illustrated.

The altering phenomena generally occur close to the surface of the ground, where the process is facilitated by surface water seeping into the ground, by the presence of carbon dioxide in this water, and by temperature variations between night and day. The decomposition of compact rocks into colloidal soil is called laterization. It takes place at much greater speed in tropical areas, and is also strongly influenced by the presence of humus on the surface of the ground.

Lateritic deposits can be associated with many types of rocks. This illustration shows a transformation from basalt, a typical igneous rock. Above the compact base of the basalt is the part that has been mechanically crushed, the rock fragments becoming smaller and smaller toward the surface and eventually becoming imbedded in material that has already decomposed. Bauxite is present in the upper part of this layer, but it is in the layer above that the mineral is concentrated and it is this stratum that is exploitable.

Above this concentration is a layer of iron-rich bauxite; the iron separates in the form of oxide, giving a characteristic reddish color to the soil.

7



SALT DOMES—Deposits of rock salt are generally formed by evaporation. Where a lagoon of salt water becomes separated from the sea, in time it may become completely evaporated, forming a salt deposit. When such a deposit is covered by layers of impermeable rock, it is protected against erosion.

Salt has a density of about 2.2, somewhat less than the density of most of the rocks in the lithosphere, which is about 2.7. If a salt deposit is covered by only a thin stratum of overburden, nothing will happen. However, where this covering layer of rocks becomes thick and heavy, the mass of the salt is subject to very great stresses caused by the downward pressure of its overburden. A characteristic of rock salt in large masses is its great plasticity. Because of this, the salt tends to be pushed upward, providing a small-scale example of the phenomenon of isostasy.

This cross section shows how the salt has been pushed upward—literally squeezed toward the surface of the ground. It has broken through all the layers of overlaying rocks and is covered by only a thin stratum of rock. All the adjacent layers of rock have been sharply bent upward, providing clear evidence of the salt's movement.

Salt mines that are often opened in these salt domes (the term "dome" is derived from the characteristic cupola form of the part of the salt mass that acts as the spearhead in breaking through the covering rocks) show that the interior of the deposit consists of layers that have been folded into very complicated volutes, because of the great compressive stresses to which the salt was subjected in its rise toward the surface. Inside the mass of the salt, it can be seen that originally horizontal layers have been horizontally compressed and folded in order to enable the salt to rise in a comparatively restricted space. Only as it approaches the surface is the block of salt able to spread out again to form a wide and somewhat flat dome. Even here, the layers of salt will again be folded into very complicated patterns.

MINING MINERALS | extracting, loading, and hauling minerals

Although open-pit (opencut) methods are the most economical for exploiting mineral deposits, they are possible with only a few minerals—coal, copper, aluminum, and a few others. Even with deposits of some of these, as with most other minerals, mining must be carried out underground, employing techniques very different from those of open-pit operations.

Underground mining requires special machinery for cutting galleries and shafts and for transporting minerals to the surface. Because each deposit has its own peculiarities, machines for extracting minerals range from those for drilling blast holes (where a hard mineral has to be mined in hard country rock) to a variety of excavators for opening galleries (horizontal) and shafts (vertical). When the mineral is soft and imbedded in soft rock, other machines are used to break it away from the country rock. Still other machinery is needed for transporting the mineral along the galleries of the mine, for lifting it up the shafts, and for conveying it to surface installations.

Mining technology requires a very detailed knowledge of the nature of a deposit so that the right kind of machinery will be chosen for the operation. Cost of machinery constitutes an important item in the economics of underground mining, but it is by no means the only expense.

Underground mining involves the removal of large quantities of materials from inside the Earth; this gives rise to two major difficulties. The first concerns the gallery itself. The roof of the gallery, under pressure exerted by overlying rocks, is always in danger of caving in, and must be properly supported. Once a gallery has served its purpose and all the useful material has been removed from that particular part of a deposit, it is often possible to backfill the gallery with waste material hauled from the surface; a simpler alternative consists of removing the props and walling up the entrance to the gallery. In either case, some settlement occurs, and where the mining

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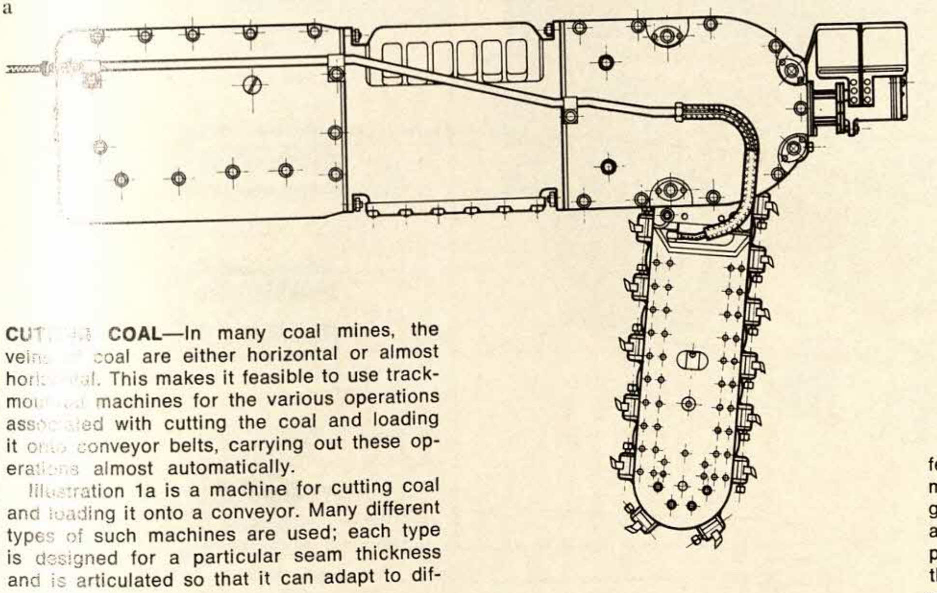
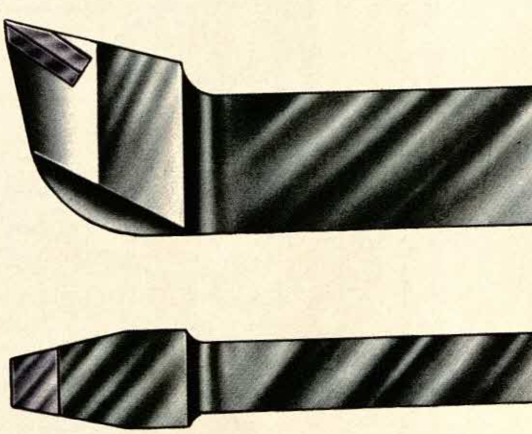




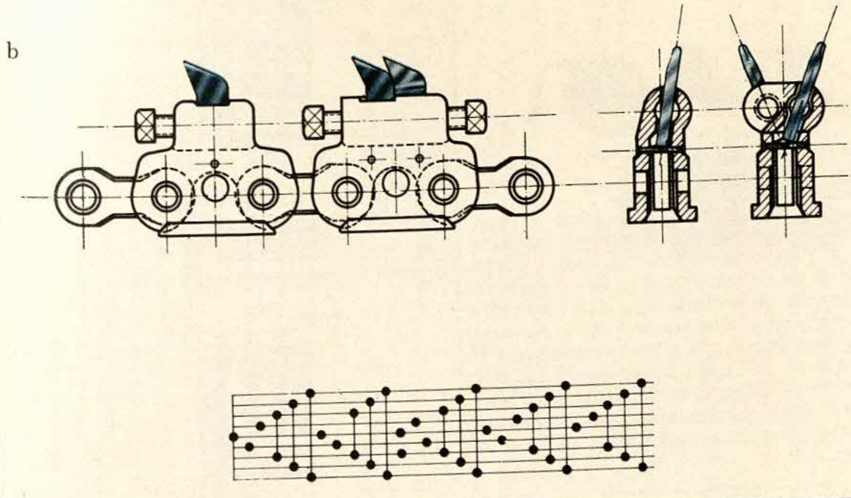
CUTTING COAL—In many coal mines, the veins of coal are either horizontal or almost horizontal. This makes it feasible to use track-mounted machines for the various operations associated with cutting the coal and loading it onto conveyor belts, carrying out these operations almost automatically.

Illustration 1a is a machine for cutting coal and loading it onto a conveyor. Many different types of such machines are used; each type is designed for a particular seam thickness and is articulated so that it can adapt to different excavation conditions. The body of the machine contains the engines, the reducing gears through which the cutters are operated, and devices for fixing the machine in a rigid position. The cutting mechanism, shown in the lower part of Illustration 1a, consists of an endless, toothed chain similar to that of a chain saw.

Illustration 1b shows some details of the chain and the cutting blades attached to it. Cutters are fixed in holders from which they can be removed for replacement. The diagram at the bottom illustrates the pattern in which the cutters are arranged on the chain; they are placed at different heights, enabling them to operate on the entire width of the seam.

Cutter bodies (Illustration 1c) are of steel while the cutting edge is of metalloceramic material welded to the end of the body. The cutters are similar to those used on a lathe although the shape of the blade and the cutting angle are specially designed for the task they are to perform.

Illustration 1d shows how the cutter-loader operates in a seam. The machine is placed alongside the material to be removed, with the cutting device projecting into the seam



is extensive, continuous settlement of the underground strata eventually leads to an appreciable lowering of the ground surface. In certain mining districts in the United States and England, this phenomenon has assumed such proportions that ground settlements have caused houses to collapse and have destroyed water mains, sewage systems, and similar underground installations. Ground settlements occurring over extensive areas can also lead to the formation of swamps or lakes by causing entire tracts of land to become submersed. For fundamentally the same reasons, similar difficulties are encountered in the vicinity of oil fields.

Another great difficulty in underground mining, one that can constitute a very acute danger, is the possibility of the mine unexpectedly striking an underground deposit of liquid or gas. The principal danger is from water, and this danger is common to all types of mines except those situated in particularly arid regions. A water strike can lead to flooding or even the complete submersion of entire galleries and shafts. The steam engine was invented for the specific purpose of providing a prime mover to pump water out of mines, a task that had previously been performed by laborious manual means. A system of drains is needed to collect the water (even if no underground watercourse is encountered, considerable quantities of water will drip into the mine) as well as pumps to lift it

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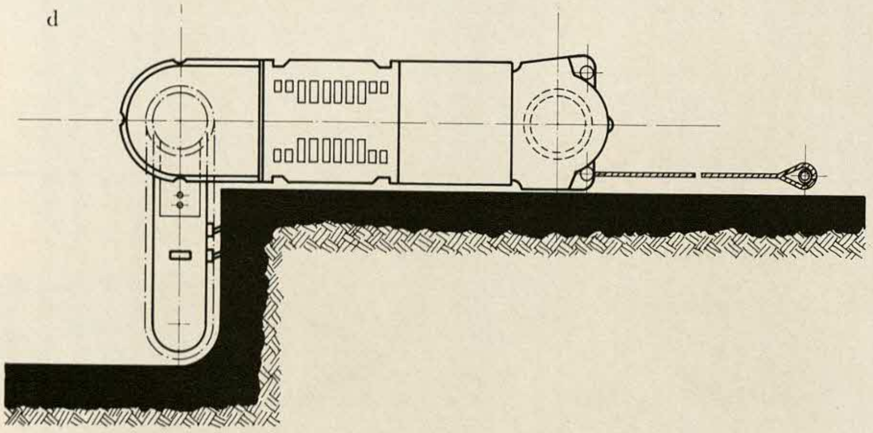

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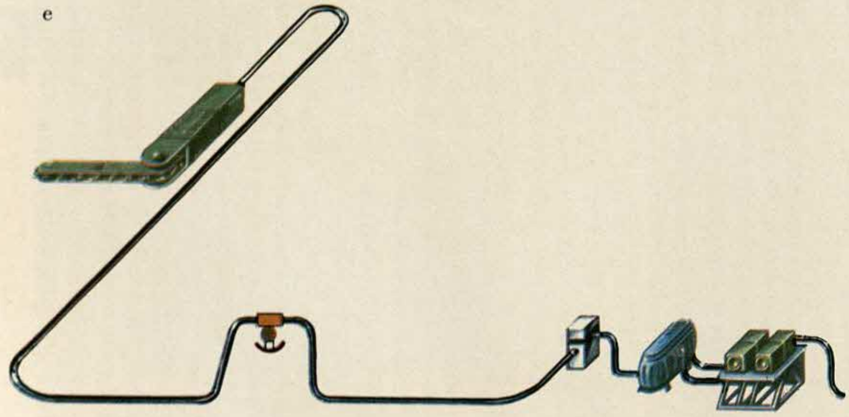

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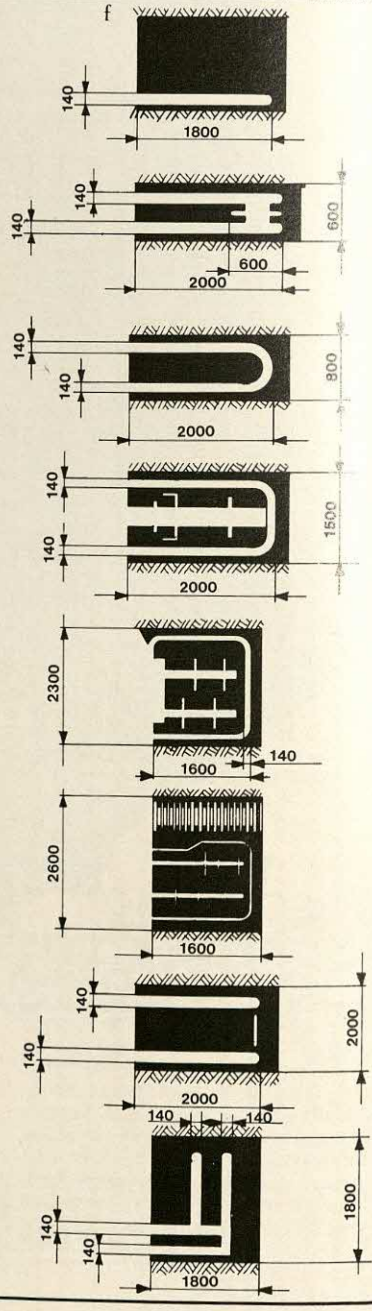

in close contact with the cutting face. The machine is anchored to a cable that pulls it forward as the cutting proceeds.

In some mining operations, electricity is used as a source of motive power for this machine, with current supplied through a cable from a small generating station. Illustration 1e shows how the cable of the supply system is arranged so that the machine can travel without imposing excessive stress on the cable or damaging it beneath the machine.

The many different paths that a cutter-loader may have to follow in passing through a large seam of coal are shown in Illustration 1f. Such a machine must be capable of a high degree of specialization that makes it suitable for a specific type of mineral or seam. Furthermore, the cost of the machine must be completely amortized before it has extracted all the mineral from the seam for which it was designed. This points up the importance of having an accurate estimate of the amount of mineral that such a specialized machine is likely to cut.

to the surface. This is a major cost factor in underground mining.

In coal mines, methane gas constitutes a particular hazard. The presence of explosive or toxic gases (these latter particularly in sulfur mines) complicates the mining process and requires a series of safety precautions. For example, explosives must be specially designed to avoid the spreading of combustion into a gaseous atmosphere. Careful control of all equipment and processes that could cause sparks must be maintained. This applies particularly to electrical power plants, which must be enclosed in hermetically sealed casings.

In coal mines, methane is absorbed in the coal and the associated strata, and it is liberated when they are disturbed. It usually is given off gradually. In the course of mining, some seams yield up to 5,000 cu ft of methane for each ton of coal. In order to render this gas harmless, it is necessary to circulate large volumes of air to reduce the percentage of methane to below a prescribed figure. Methane may also be given off in the form of outbursts—sudden, violent discharges of short duration, usually accompanied by the displacement of large quantities of dust and broken strata. Although serious outbursts are rare, dangerous accumulations still occur despite detection and ventilation techniques. As a result, methane gas remains a major hazard.

Machinery for extracting coal may cause a strong concentration of coal dust. Such dust is harmful to respiration and is the cause of miners being particularly prone to pulmonary diseases of the silicosis type. High concentrations of coal dust are also serious explosive hazards. Thus it is essential that mines be adequately ventilated.

Another problem in underground mining is that of energy sources. The use of electricity in mines is severely restricted and even prohibited in some countries, primarily because the supply cables of mobile machinery are liable to damage and submersion in water. The operation of mining machinery generally requires relatively high voltage, thus creating a hazard because miners often work in contact with water or handle wet materials.

The internal combustion engine is practically excluded from use in mines,

MACHINES FOR CUTTING CIRCULAR SECTIONS—Certain types of machines are used for cutting circular sections in galleries. The operational mode of such a machine is essentially that of milling the mineral. The model shown is for a coal mine. The entire face of this machine is made up of a large cutter consisting of many blades of the type illustrated previously. The blades excavate the coal as the machine rotates; at the same time the machine effects the removal and loading of the excavated material. The cutting disk is continually pushed forward. The same machine can also be used for cutting materials that are harder than coal or the rock in which it is usually imbedded, although both the type and arrangement of the cutting blades are usually changed. A similar machine is used for excavating tunnels for roads, railways, and so forth.

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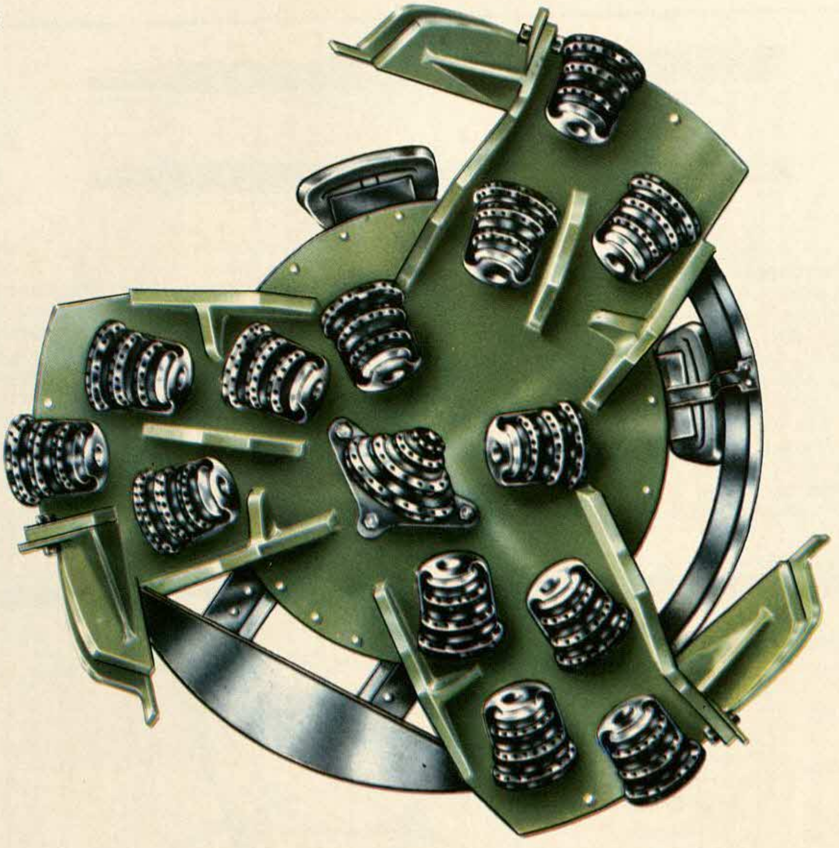

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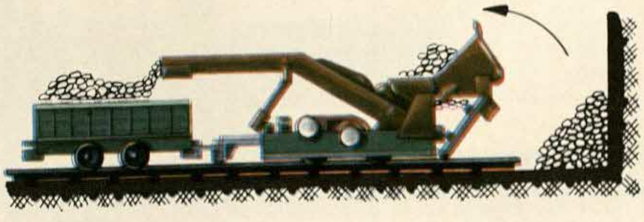

LOADERS—Where a mineral is being excavated by cutting machinery or by explosives, it is generally necessary to have machines to load the loose mineral. The illustration shows a machine designed to load narrow-gauge rail trucks. A loading shovel discharges the material into a hopper that continuously feeds a conveyor belt that drops the material into the truck.

One problem in the design and construction of such a loader is insuring that it will be able to operate efficiently in an area of limited height, an inevitable consequence of the small space in a normal mine gallery.

except in rare cases where it is possible to install a very efficient ventilating system capable of completely evacuating the highly toxic exhaust gases. Generally, this is only possible in very wide galleries with a permanent ventilating system; it is rare for such conditions to exist at the digging face of the mine.

The most commonly used source of energy in mining is compressed air. Air compressors can be installed [illegible] locations where it is possible to take [illegible] necessary safety precautions to protect both miners and equipment. The compressors can be installed underground and, [illegible] properly

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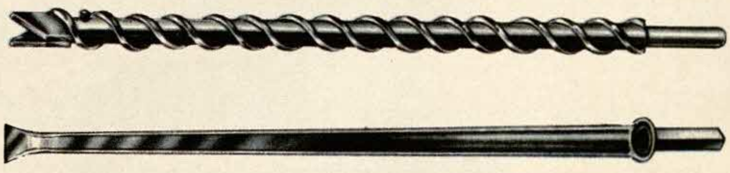

THE USE OF EXPLOSIVES—Explosives are a powerful tool for obtaining hard minerals imbedded in hard rock. The techniques of mining with explosives are similar to, but not wholly identical with, those usually employed for driving road tunnels.

Illustration 4a shows the two principal types of bits used for drilling holes in which explosive charges are set off in order to loosen the mineral. The first, a bit for a rock drill, cuts holes by rotation; the second is in the form of a chisel and cuts by means of percussion.

A mobile platform mounted on rails (Illustration 4b) is used to make rapid progress in driving a gallery; it carries the pneumatic hammers used to drill the holes in the face of the gallery, holes into which explosive charges are placed. The platform contains a number of articulated arms so that the hammers can be placed against any point of the gallery face. These arms can also be used to drill holes in a lateral direction. The machine follows the hammers as they penetrate into the rock or mineral. When the drilled holes are at the desired depth, the platform [illegible] removed. Charges are then placed in the holes and set off. The loader is then brought u[illegible] loose material is removed, the floor of the gallery is trimmed to the proper shape and level, and the rails are extended into the new length of the gallery. The drilling platform is then moved forward again and the cycle of operations is repeated.

The holes made in the face of the gallery must be of a specific form, especially when the rock to be blasted is hard. The depths of the holes depend on a large number of factors. Drilling must be very accurate, and the bits generally have to be changed as the depth of the hole increases. The pattern [illegible] which the holes are arranged is also important; both their position on the gallery face and their inclination with respect to the [illegible] must be estimated accurately.

The series of drawings in Illustration 4c shows how holes are arranged to permit a uniform distribution of the explosive; [illegible] diagrams

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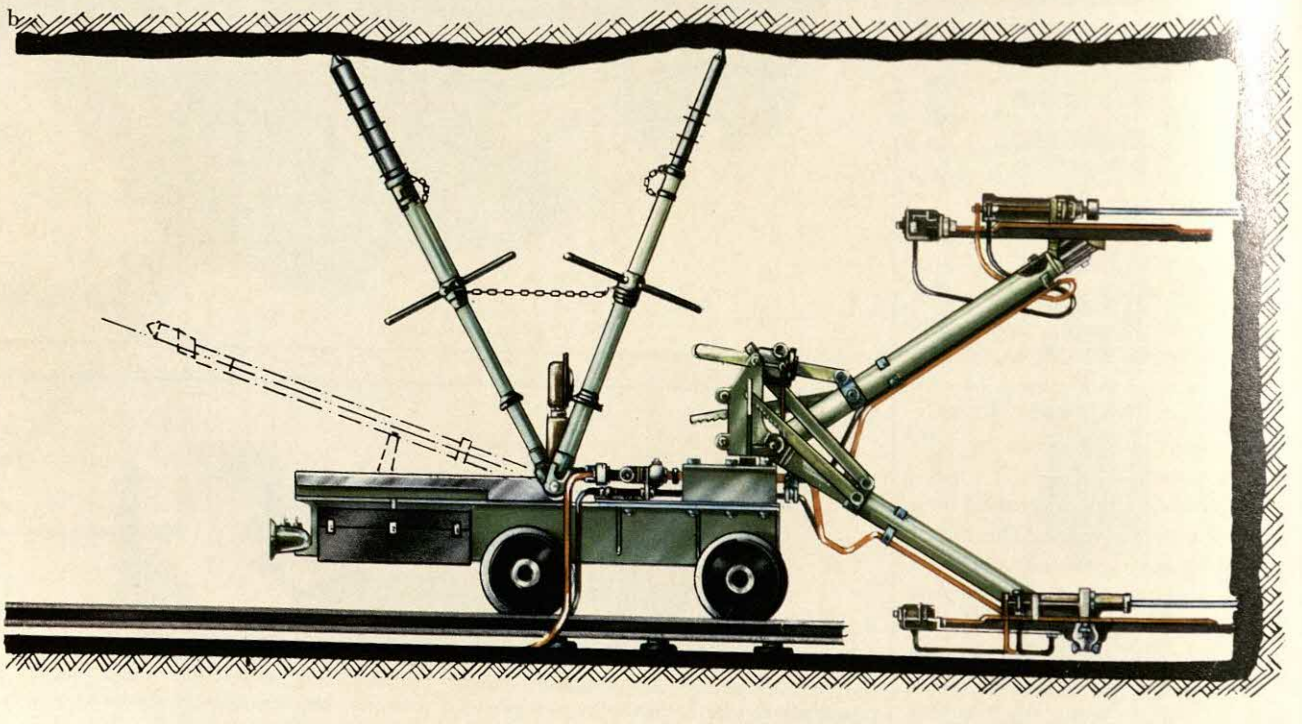

insulated, can be operated electrically. The great disadvantage of compressed air is that it involves a considerable loss of power; the power that can be transmitted to a machine is much less than the power output of the compressor—frequently amounting to less than 50 percent. Nevertheless, the safety advantages of compressed air are so great that the power loss is readily accepted even in cases where, because of the characteristics of either the mineral or the deposit, mining operations require the use of considerable quantities of energy.

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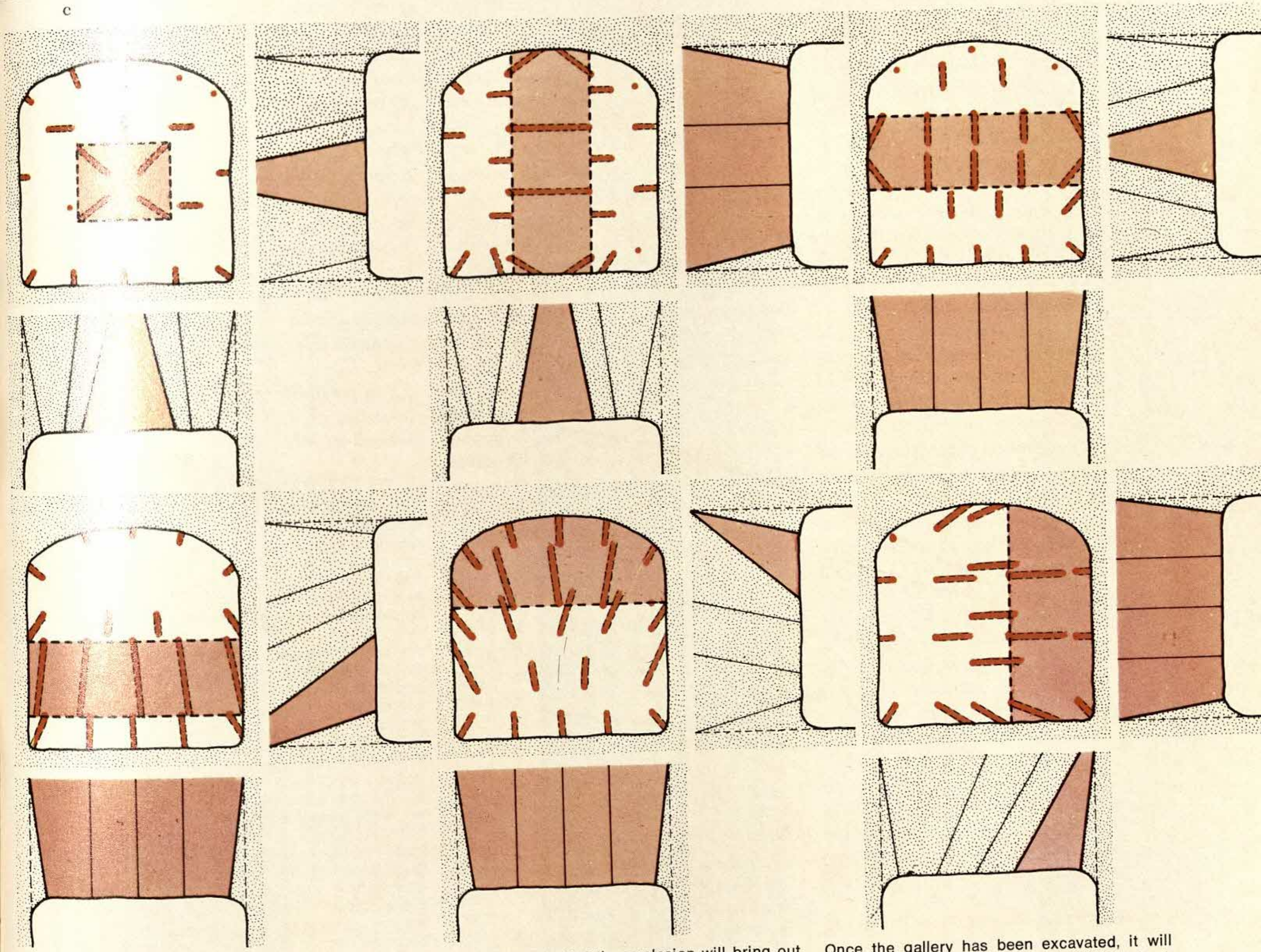

show both the position and the direction of the holes. Proper arrangement of the holes allows minimal use of explosive material—both a safety and an economic measure. The holes are placed so that the explosion will bring out a single block of material, shattering the rock all around. The pattern of holes is also determined by local conditions of the rock strata. Once the gallery has been excavated, it will have to be propped, ventilated, and drained, in order to permit the excavation to continue.

MINERAL DEPOSITS | natural deposits of raw materials

Throughout the ages, the availability of mineral deposits and man's ability to exploit them have determined the degree of civilization. Even today, the economic and industrial development of a region is closely tied to the exploitation of that region's minerals. Every human activity is vitally dependent on natural raw materials from which to forge tools, construct machinery, and create the infinite variety of manufactured items that are an integral part of modern living.

All of the Earth's surface is formed of rocks that are agglomerates of minerals. Each type of rock is characterized by a certain composition; in some areas, certain mineral components are particularly abundant. If it is commercially desirable to extract this mineral, a mine is opened at the point of highest concentration.

The local concentration of a mineral in quantities that can be usefully and economically exploited by mining is called a mineral deposit. This definition is rather elastic, because the exploitability of a mineral concentration depends on a large number of geographical, economic, and technological factors.

The term mineral should also be defined. In the mineralogical and crystallographic sense, a mineral is a material with both a definite chemical composition and crystal structure. For example, magnetite and hematite (two different oxides of iron) are regarded as two different minerals. The extraction of iron is technologically possible from both these minerals; a deposit containing both magnetite and hematite is exploited by mining both these minerals together with the rock that contains them as well as other minerals. In mining jargon, the material thus extracted is ore containing, say, 10 percent hematite and 30 percent magnetite.

THE ECONOMIC EXPLOITATION OF MINERAL DEPOSITS

The economic value of a mineral deposit depends on a number of factors of varying degrees of importance. The prime factor is quality: the deposit must contain a high percentage of the mineral to be extracted. The absolute value of this percentage depends on the particular element, and the range varies widely, depending on whether the element is a base one such as iron, or a precious one such as silver, gold or platinum.

Two deposits with the same concentration of the same element may still have different values if the gangue (the complex of all other mineralogical species that accompany the desired element) differs. The nature of the gangue greatly influences the ease or difficulty with which the useful mineral can be separated from nonuseful ones.

Another important factor is the way the useful element is distributed within the gangue. It may be concentrated in large blocks, or it may be dispersed in fine particles that are either hard or friable; each situation requires unique methods of mining and processing. The presence of other elements in addition to the principal one also influences the value of the mineral deposit. For example, copper is frequently found along with silver, platinum, and palladium; a high percentage content of these metals may make the extraction of the principal element, copper, more economically advantageous. However, the presence of these metals could also have the opposite effect; if they can be separated from the copper only through very costly processes, then these impurities will exercise a negative influence on the economics of mining the copper.

The size and form of a deposit must be considered in assessing its value. A small deposit with a high percentage content of the desired mineral may be less suitable for exploitation than a large one with a lower content, because large deposits often make possible the use of more economical methods of extraction. A very large deposit may make it feasible to design and construct special machinery suited to that particular deposit.

Unforeseen situations arising from price variations on the international mineral markets sometimes make it advantageous to reopen an idle deposit, just as they may lead to the closing of mines that were formerly profitable.

Still another factor influencing the exploitability of a mineral deposit is the nature of the rock in which the mineral is embedded, and whether the mineral can be obtained by open-pit mining or has to be mined underground. When open-pit mining is possible, it is advantageous if the embedding rock is friable; mining can then be carried out with ordinary excavating equipment, with belt conveyors providing a ready means of transporting the excavated material. When mining must be done underground, however, excessively friable rock becomes a disadvantage, requiring heavy bracing of the mine walls and roof. On the other hand, if the embedding rock is very hard, the excavation of shafts and galleries may become costly because of excessive wear to drill bits, the large quantities of explosives required, and so forth.

The possibility of running into large quantities of water in a mine, with the consequent necessity of providing ap-

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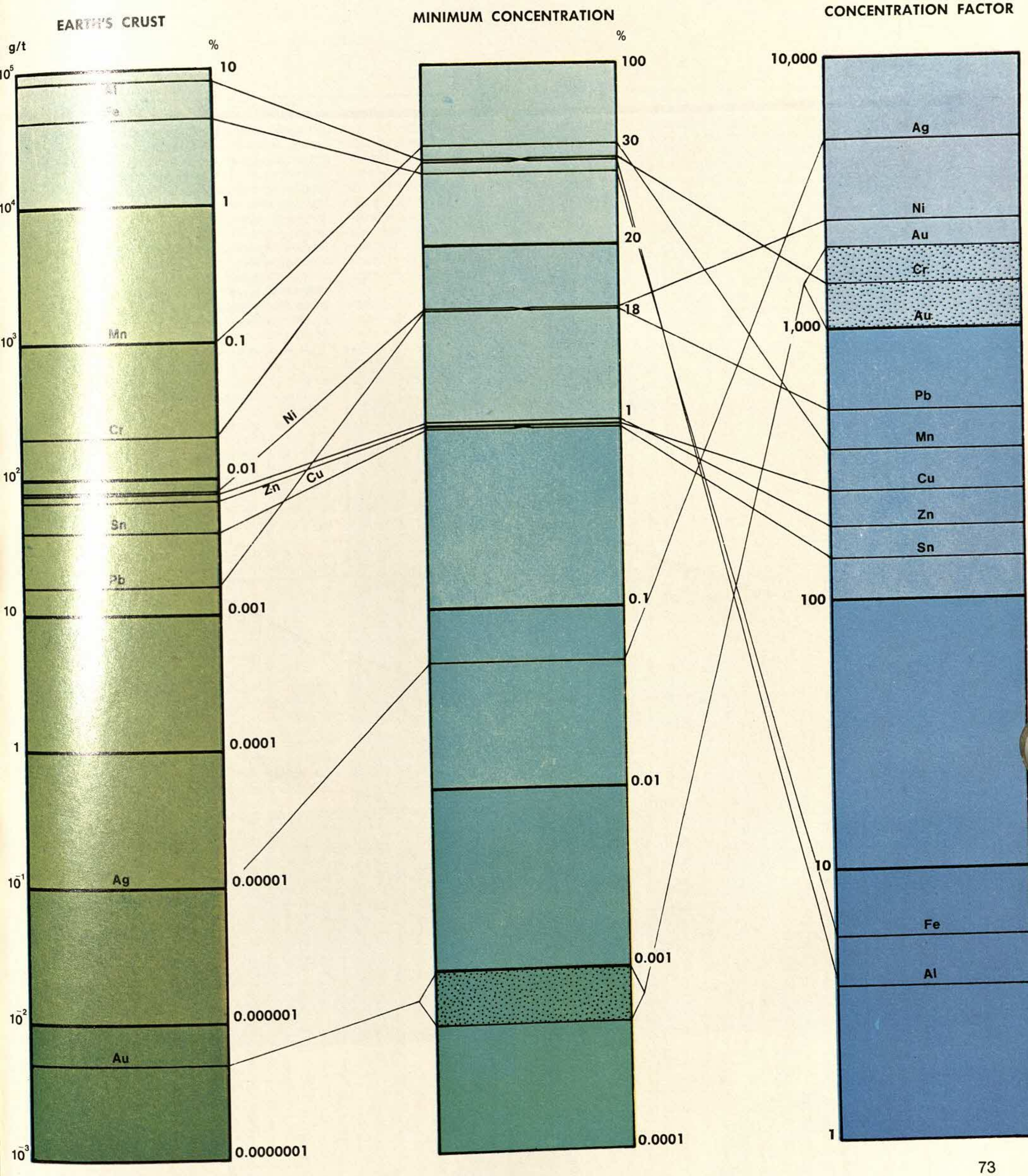
THE CONCENTRATION FACTOR—This diagram illustrates the abundance of certain elements in the Earth's crust and the minimum concentration generally required before a deposit of one of these elements can be economically exploited. Not every deposit of this concentration will actually be exploitable. For example, if the size of the deposit is very small, the cost of extracting it may be prohibitive. On the other hand, very large deposits may be economically exploitable even though the concentration is somewhat less than the figures shown.

The first column shows the abundance of these elements in grams per ton (on the left) and as a percentage (on the right). The second column shows the minimum concentration that will make a sufficiently large deposit economically exploitable. The third column relates these two values—that is, it shows how much more abundant the element must be in the deposit than it is in the Earth's crust to make it exploitable. This concentration factor, rather low for such elements as iron and aluminum, becomes enormous for such rare elements as gold, silver, and lead. (It is interesting to note that such elements as copper, tin, and lead are classified as precious metals.) The minimum concentration factor is determined not only by the rarity of the element, but also by the techniques available for mining the material and the chemical methods for extracting the element from the material. As advances are made in these fields, the minimum concentration factor will be lowered, making it possible to exploit less concentrated deposits.


EARTH'S CRUST
g/t
%
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Al
Fe
10^4
1
Mn
10^3
0.1
Cr
10^2
0.01
Sn
Pb
10
0.001
1
0.0001
10^{-1}
Ag
0.00001
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0.000001
Au
10^{-3}
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Ni
Zn
Cu
MINIMUM CONCENTRATION
%
100
30
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18
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CONCENTRATION FACTOR
10,000
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Ni
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Cr
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1,000
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Cu
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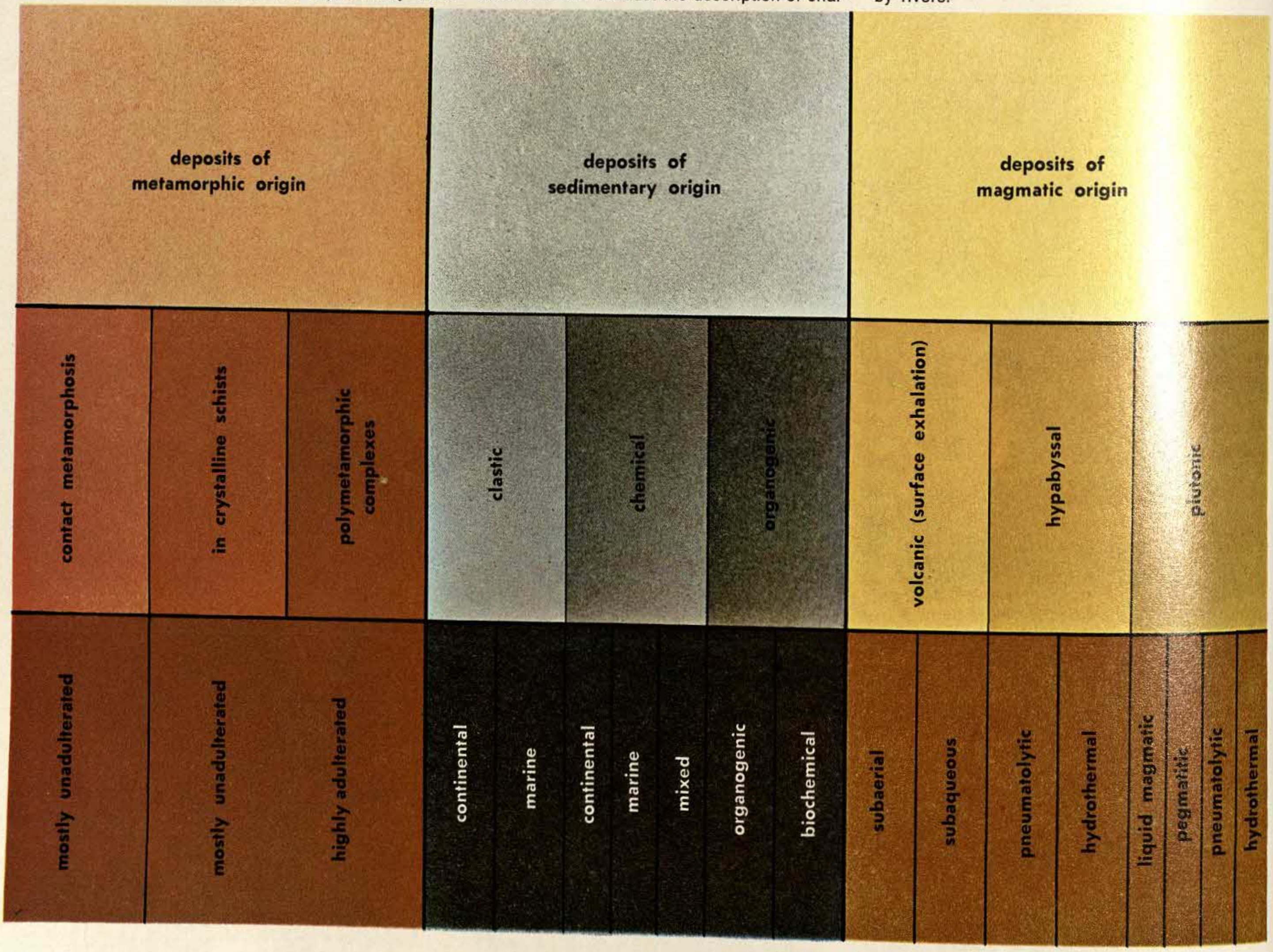
2

PRELIMINARY CLASSIFICATION—Knowledge of the type and nature of a deposit indicates its structure and suggests criteria for its exploration and possible exploitation. The first broad subdivision classifies the deposits as magmatic, sedimentary, or metamorphic.

Magmatic deposits are further subdivided into plutonic, hypabyssal, and volcanic deposits, according to the type of magmatic activity through which they originated. Magma cooling at a certain depth may have formed a deposit without appearing on the surface; or, a deposit may have been formed by magma penetrating toward the surface, forming a sill or dike subject to complex interaction with surrounding rocks; or the deposit may have been formed by the passage of gases liberated from the magmatic basin of a volcano.

Sedimentary deposits are subdivided into clastic, chemical, and organogenic. Subdivision of metamorphic deposits is somewhat more complex. This history of transformations undergone by metamorphic rocks is still largely unknown; many causes could have produced an exchange of elements between the rock containing the original mineral and the surrounding rocks, and the mineral may, therefore, contain additions derived from these other rocks.

The classification shown covers practically all possibilities, even the exceptional ones, but it does not exhaust the description of characteristics of mineral deposits. For example, a deposit may be either syngenetic or epigenetic according to whether it was formed at the same time as the surrounding rock or at a later time. It is also important to determine whether a particular deposit is primary—one that has not undergone any transformation or movement after its original formation—or secondary—one formed from the minerals of a primary deposit that has been either destroyed or strongly modified. Deposits of gold and diamonds are often secondary deposits and are frequently found in alluvial sands; in such cases, the minerals were eroded from the rocks in which they were formed and carried away by rivers.



THE CLASSIFICATION OF MAGMATIC DEPOSITS—It is important to know the origin of a deposit in order to be able to evaluate its nature, its probable extent, and the directions in which it extends—that is, the location of the so-called probable mineral.

Illustration 3a, a cross section of a magmatic deposit, shows a plutonic formation that contains within, or by the side of its mass, concentrations of useful minerals. These elements are represented principally as bodies differentiated from the mass or bodies that have moved toward the surface through cracks in the plutonic formation or in the rocks in which they are contained. The vertical extent of the plutonic formation is considerable, reaching a depth of 10 km (about 6 mi) or more. In plutonic formations too recent to have been bared by erosion, the greater depths are unimportant. However, a deposit that was once at a great depth will have been greatly altered, and will assume a form that readily distinguishes it from deposits formed at lesser depths.

Deposits exposed at the top of the plutonic formation are called acrobatholitic, while those nearer the bottom are called hypobatholitic. Other zones of the batholith in which deposits are formed are identified in the illustration; these zones are characterized by different temperatures and, consequently, by the prevalence of different phenomena due either to solidified magma or to the gases and liquids that separated from the magma's colder parts closest to the surface.

Illustration 3b shows volcanic and hypabyssal deposits, formed as a result of the presence of magma at or near the surface because of volcanic action. The principal difference between these and plutonic deposits is due to their interaction with surrounding rocks and to phenomena that occurred at much lower temperatures and pressures than were associated with the formation of the plutonic deposits. While magma rising upward through volcanic passages may have had very high temperatures, these would have cooled quickly both because of the small mass of magma in the passages and because the thin overlying rock layers separating the mass from the surface readily permitted the heat to escape.

Hypabyssal or intrusive bodies were thus formed between the magmatic mass and the surface, while volcanic deposits were formed wherever the magma actually reached the surface of the ground.

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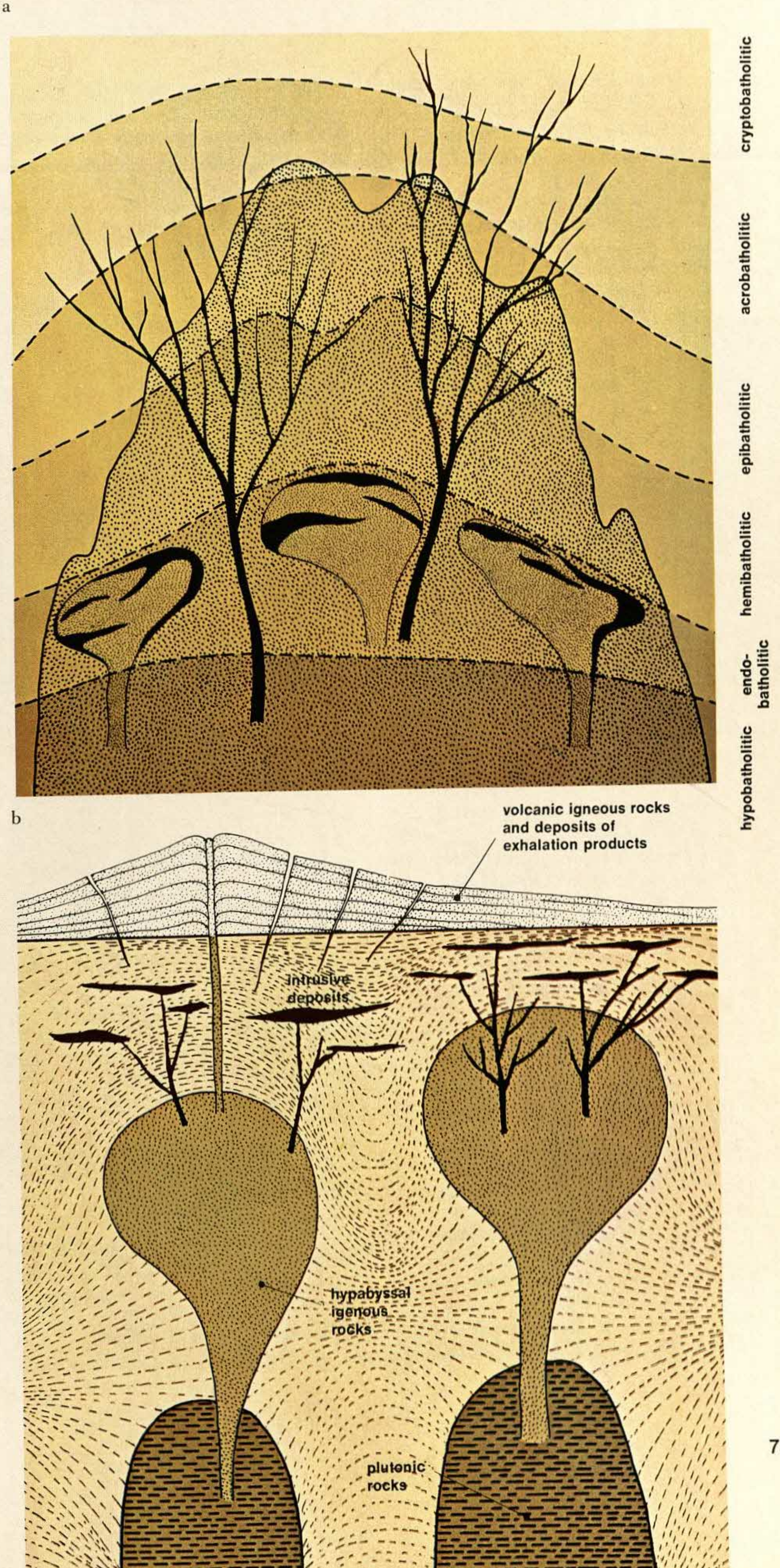

propriate drainage, represents another cost factor that must be considered, and points up the need for thorough geological survey of a region before attempting to exploit its mineral deposits.

Finally, geographic location influences the economic value of a mineral deposit. Until relatively recent times, most exploitable mineral deposits were situated near inhabited areas, where they had been worked for many years or even centuries. Over the past several decades, however, important deposits have been discovered in remote regions; in many cases where mining was economically feasible, small mining communities developed into important cities.

The present tendency to mine large deposits even when the concentration of the useful element is comparatively low emphasizes the great importance of geographic location. In Canada, for example, it has been possible to exploit vast deposits of aluminum because they were relatively close to sources of hydroelectric energy (electricity is a basic requirement for the production of the metal). Relatively short transmission lines transport the electricity to the processing plants—far cheaper than having to transport the mineral great distances from the excavation site to the processing plant.

This problem was particularly evident in the development of the modern steel industry. Germany, England, and certain parts of the central United States were fortunate in having deposits of iron minerals and coal that were relatively close together (the coal is needed in large quantities to fire blast furnaces that extract the iron from its ore); neither material had to be transported any great distance.

PROBLEMS OF THE MINING INDUSTRY

Many difficult problems must be solved before a mineral deposit can be successfully exploited. First, of course, geographic research and exploration must be undertaken to discover the deposits. Next, the quantity and economic importance of the deposits must be evaluated. The amount and form of that part of the deposit that cannot be immediately ascertained must be estimated. Then, should prospects appear favorable, a method of extraction must be planned. Finally, the actual mining takes place. Subsequent stages in the processing of the mineral are not directly connected with the geologic problems.

Once a deposit has been discovered and the mineral in view evaluated, the mine itself must be planned on the basis of both the primary mineral and whatever secondary minerals there might be. During the mining, geological criteria must be employed that will assure concentration on the most productive areas and minimize the handling of useless material. Thus, geological knowledge is a vital component of successful mining operations.

DISTRIBUTION OF MINERAL DEPOSITS

The economic and industrial development of nations depends to a great extent on the availability and accessibility of natural resources. Therefore, the manner in which minerals are distributed often has far-reaching implications.

Iron and steel, of course, have enormous industrial importance in the world today. Iron is the second most abundant metal in the Earth's crust, exceeded only by aluminum. Although iron as an element is widely distributed, the major iron minerals (hematite, magnetite, limonite, and siderite) are concentrated in ore deposits in a limited number of places. The richest ores, consisting principally of magnetite, contain 60 to 70 percent iron. Hematite deposits rarely contain more than 60 percent iron, and some poorer ores often contain as little as 20 percent iron. Ordinarily, recovery of iron from ores containing less than 25 to 35 percent of this metal is considered uneconomical. Among the countries possessing important iron deposits are the United States, Peru, Canada, Venezuela, Chile, Brazil, France, the United Kingdom, Germany, Sweden, the Soviet Union, China, India, and North Korea.

The ferroalloy metals, which are used in limited quantities in the production of specialty steels, are much more limited than the iron ore deposits. Considered together, they are widely distributed among many nations, but the principal steelmaking countries rely heavily on imports to satisfy their needs. For example, the United States produces only molybdenum and vanadium in sufficient quantities to meet its requirements. The other ferroalloys—manganese, nickel, chromium, and tungsten—must be imported.

More than half the world's nickel comes from the Sudbury region of Canada, and over three fourths of the world's molybdenum comes from the United States—primarily from deposits in Colorado.

Increasingly the nonferrous metals have become important to industry. Copper, which has a long history of use, is one of the most important nonferrous metals today. Leading copper producing countries include the United States, Canada, Chile, Peru, Australia, the Soviet Union, and the Democratic Republic of the Congo.

Aluminum is currently in wide use because of its electrical conductivity, its lightness, and its resistance to corrosion. Deposits of bauxite, the major source of aluminum, are found in the United States, the Soviet Union, France, the Republic of Guinea, Jamaica, Surinam, and Guyana. Aluminum was not considered economically important until fairly recent times, when relatively inexpensive methods of separating the metal from bauxite and other aluminum-containing minerals were developed.

Zinc, tin, and lead are three other important nonferrous metals. Almost a third of the world's metallic zinc is produced in North America, while Europe accounts for about 20 percent of the world's zinc-ore production. Tin ore is highly concentrated in a few areas of the world, and Bolivia is the only major source in the Western Hemisphere. The United States, Canada, Mexico, Peru, Australia, the Soviet Union, China, and South Africa are leading lead producers.

Deposits containing gold, silver, platinum, and other precious metals and deposits of sulfur and certain other nonmetallic minerals are unevenly distributed around the world.

THE GENESIS OF PLUTONIC DEPOSITS— This is a more detailed version of Illustration 3a, showing most of the known phenomena that can cause the formation of a deposit in a plutonic complex. Not all these deposits are found in and around every plutonic formation, and there may well be cases of plutonic complexes where none of them has occurred. Nevertheless, the large variety of the forms of deposits shown is striking.

The fissure toward the right side of the illustration extends from the plutonic mass right up to the surface. If minerals have been deposited in this fissure, it is termed a vein or lode. Within veins, various conditions of pressure and temperature encountered as the magmatic mass rose to the surface have led to the formation of different minerals at different depths. A geologist encountering such a vein in a mine will have access to only a very small part of it, but by knowing that the vein is of plutonic origin, he will be able to determine at what depth the mineral formed. From this, he will be able to deduce with reasonable accuracy what kinds of minerals are likely to be found in the vein above or below the access point.

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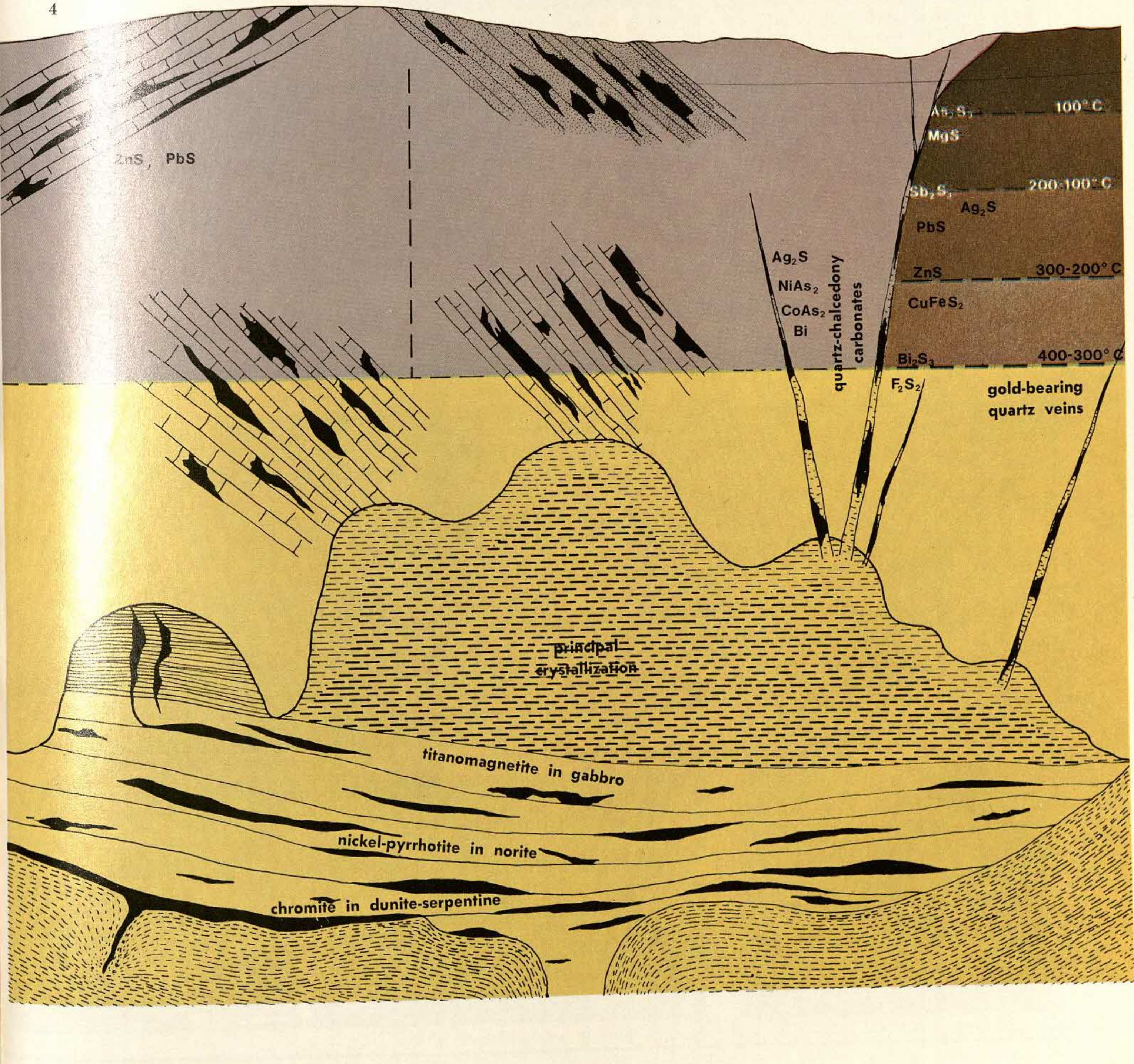

GEOLOGICAL EXPLORATION | purposes and survey methods

The word geology—the study of the Earth as recorded in its components—has been known for centuries. Not until 1795, however, was the science of modern geology born. In that year, James Hutton, a retired Scottish physician and farmer, published his *Theory of the Earth*, in which he ascribed rational causes to the changes that were evident in the surface of the Earth.

Since that time, geology has come a long way. Huge construction and mineral extraction industries depend on geological exploration for their survival and success. Geologists tell contractors where

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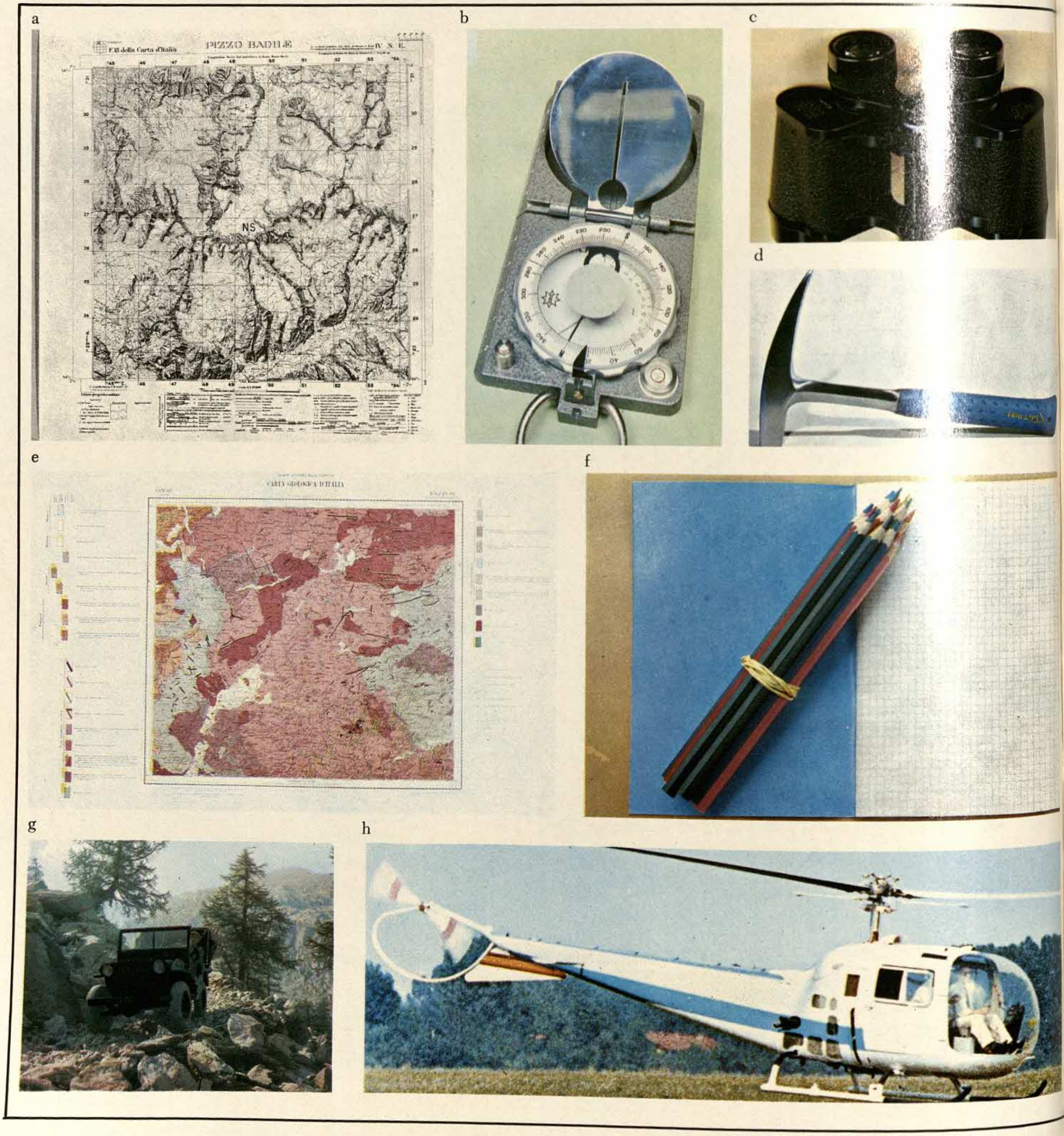

to dig for gravel and stone; they help oil companies determine where to sink their wells; and they tell miners where and how to look for minerals.

Geological exploration aids in determining the conditions of the ground prior to beginning large construction projects. Geologists also study the geological evolution of an area so as to predict potential damage from earthquakes and other ground movements.

PRACTICAL APPLICATIONS OF GEOLOGICAL PROSPECTING

Strictly speaking, field geology consists of surface observations of a particular section of the Earth. Only rarely does the geologist have the opportunity of checking his observations by going underground. Geological prospecting aims at finding outcrops of certain rock strata where specific minerals may exist. The exploration geologist is concerned both with finding the type of rock that contains the mineral being sought and with the quantity or quality of the mineral deposit itself. The exploration geologist also designates the areas that have the greatest potential for further study. He suggests guidelines for a detailed survey and often suggests locations for trial borings or excavations.

Often, instead of concentrating his attention on the search for a particular mineral, a geologist may carry out a general survey of all the geologic phenomena in an area. He may prepare a map of such geological phenomena as outcrops of rock, characteristics of the bedding of rock layers, directions and patterns of the schists, and the trends of tectonic phenomena—that is, the relationships between the strata, the relative age of various types of rock, and the presence of folds, faults, and other features of the area.

TOOLS OF THE GEOLOGIST—Illustrated are some of the instruments and vehicles used by geologists in their explorations.

Illustration 1a is a topographical map that shows configurations of an area in exact detail, including relief, positions of streams, roads, and cities.

Illustration 1b is a geologist's compass, used to determine the direction of rock strata. The compass must be reliable, but a relatively inexpensive model usually suffices for exploration. Magnetic deviations are not critical to this type of exploration. Rough handling is often a problem, so that durability is more important than great accuracy. The compass shown is equipped with a clinometer, an instrument for measuring angles of elevation. This, too, gives only an approximate reading.

Binoculars (Illustration 1c) are useful for preliminary surveying and rough conclusions can be made about the morphology of the area.

Illustration 1d shows an indispensable geological tool—a hammer. It is used to break the surface layers of outcropping rocks to expose the unweathered layers beneath. It is also used to obtain small specimens for the laboratory, where they can be analyzed and cataloged. The hammer shown weighs about 2 lbs and is used on soft sedimentary rocks. For igneous rocks, a heavier hammer is usually necessary.

Illustration 1e is a geological map showing the overall geological features of an area, and serves as a starting point for detailed exploration, as well as a record of the geologist's findings.

A notebook and colored pencils (Illustration 1f) are indispensable for jotting down data as a survey proceeds. Each of the various formations found is assigned a certain color and filled in as such on the geological map. A legend on the margin of the map identifies the color codes.

An overland vehicle (Illustration 1g) is the best form of transport for most geological expeditions. When the cost of the project justifies it, a helicopter (Illustration 1h) is a valuable addition to the geologist's arsenal. A helicopter gives the geologist a good overall viewpoint from the air in addition to allowing him rapid transport to the inaccessible areas.

2

THE SAMPLE—Often the field survey must be supplemented by laboratory analysis of the rocks found in the area. Because representative samples must be fresh and unweathered, they are obtained from below the surface layer of rock. Each sample should be preserved in a waterproof container with a label specifying the place where it was found.

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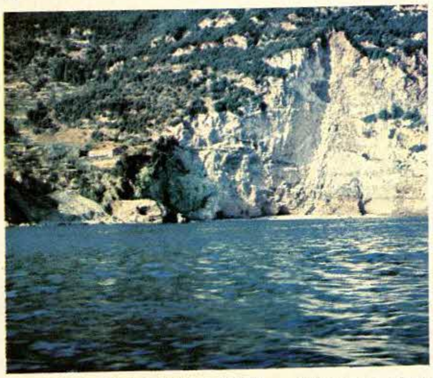

LOOKING FOR OUTCROPS — Outcrops often occur even at low altitudes where vegetation covers the ground. Because an outcrop exhibits naked rock layers, it is a valuable source of information to the geologist. From studying the outcrop, a geologist can tell whether a sought-for mineral is present, in what quantity, and of what quality.

FIELD NOTES—In geological prospecting, as in other time-consuming observations, it is important to take careful notes of all observed phenomena. An example of a detailed field record is shown here. The notes serve as a basis for transferring the data to a precise geological map.

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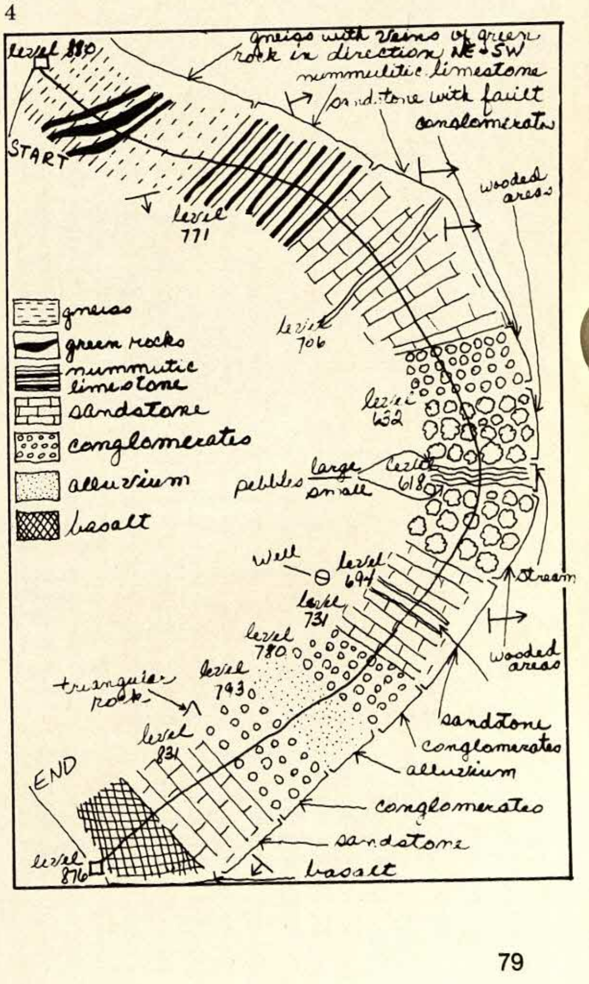

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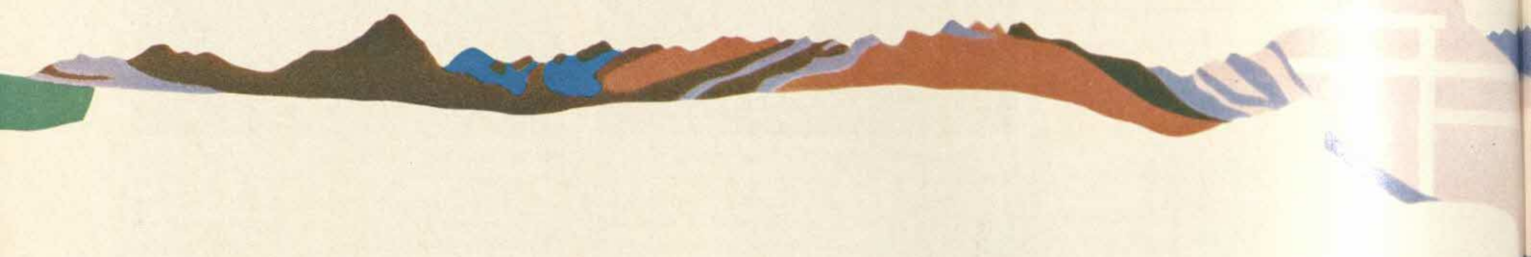
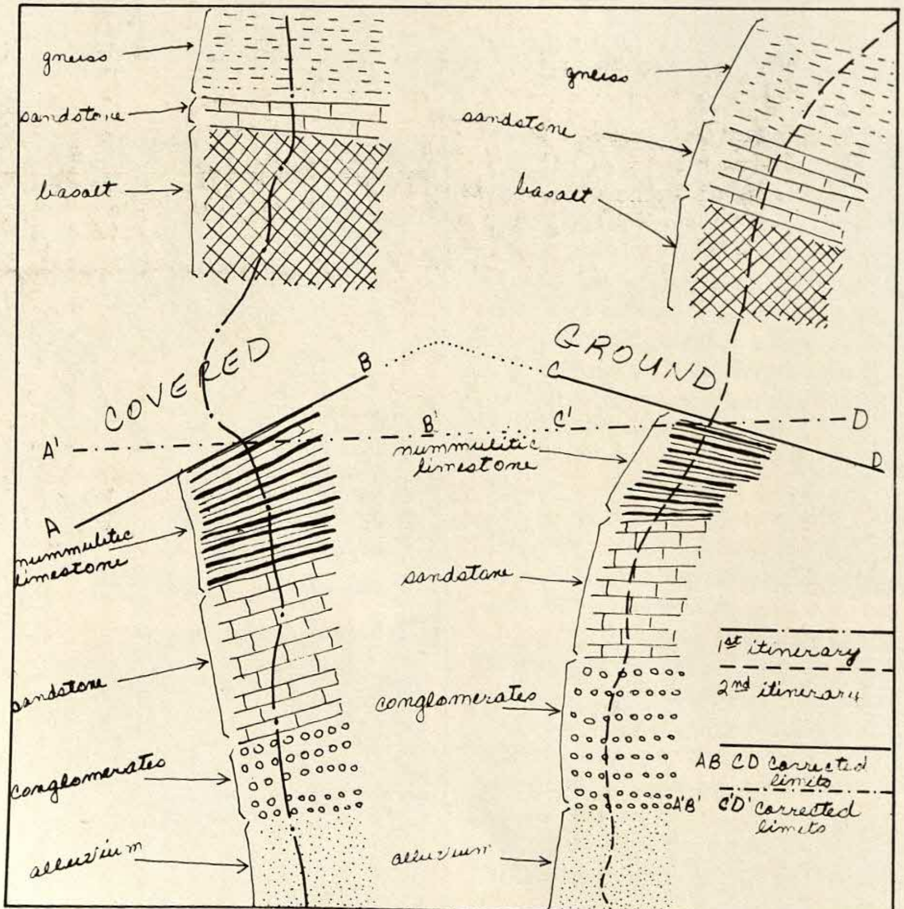


THE GEOLOGICAL SECTION—A geological section is used either for basic research or directly for prospecting. It is a view in a particular vertical plane. When the geographical exploration has been limited to surface characteristics, the strata of

The typical geological survey is undertaken so that engineers will be able properly to design large civil engineering projects such as dams and airports. In such cases, very detailed maps are drawn of the immediate construction site, with more regional maps of the surrounding area.

6



ASSEMBLING FIELD NOTES—The geologist can only work in one direction at a time. He will, therefore, construct more or less parallel itineraries and fit them together in the laboratory to make a complete map, interpolating or adjusting the limits between formations.

In designing an airport, for example, engineers must know the exact nature of the terrain. It must be as flat as possible and as open as possible in the approach areas. Furthermore, the ground must be relatively homogeneous to a certain depth and should not be excessively permeable. A thorough knowledge of the effect of rainwater and watercourses is essential for solving drainage problems and ensuring the stability of the ground beneath the runways.

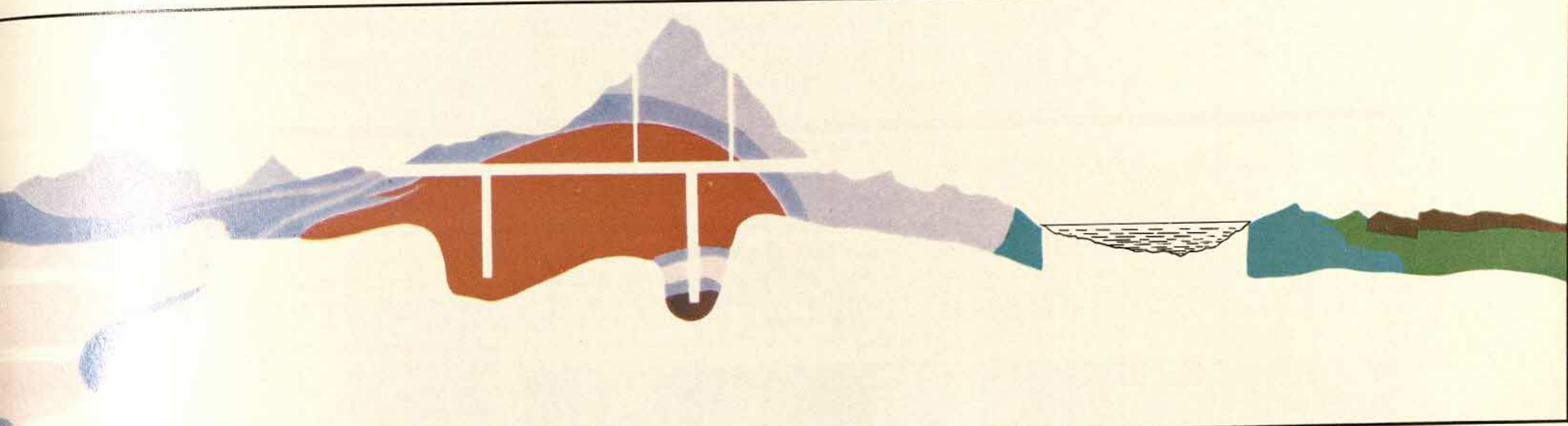
Less difficult projects are surveys for road and bridge construction. The geological nature of the ground may suggest construction variants that will effect considerable long-range savings through prior anticipation of maintenance or other problems.

Another practical use of geological exploration is for human settlement. Dwellings should be as free as possible from the threat of flood, earthquake, and landslide. If possible, roads and railbeds should avoid scree slopes where vibrations of the vehicles will cause destruction of the roadbed.

GEOLOGICAL, GEOPHYSICAL, AND GEOCHEMICAL PROSPECTING

To verify many of his findings, the geologist must utilize the supplemental sciences of geophysics and geochemistry. No fixed division exists between these sciences.

Geophysical prospecting is concerned with exploration beneath the rock surface and makes use of physical methods.



the map will be at a very shallow depth. If there are mines or tunnels as shown in this example, the geologist is able to go belowground and, therefore, include a much greater depth on his section. Each of the colors shown indicates a particular type of rock stratum.

For example, the elastic behavior of rocks may be studied by means of artificially propagated seismic waves. Magnetism and density of rocks can be analyzed by means of the irregularities that they cause in the observed gravity and in magnetic fields.

Geochemical prospecting, on the other hand, makes use of correlations between many chemical analyses of the ground. The geochemical explorer looks not only for the sought-after element, but he studies the samples for traces of elements usually associated with the material he is looking for.

Geophysical data and geochemical data substantially increase the validity of the geological survey. They are usually confined to the second stage of the survey, after the more general geological conclusions have been tentatively drawn.

THE DETAILED MAP—This topographical map represents the result of a geological exploration. Notations from the field map are transferred to the detailed topographical map. The geologist draws the limits of the various outcrops on the map with dotted lines, then colors the map so that identical formations will all have the same color.

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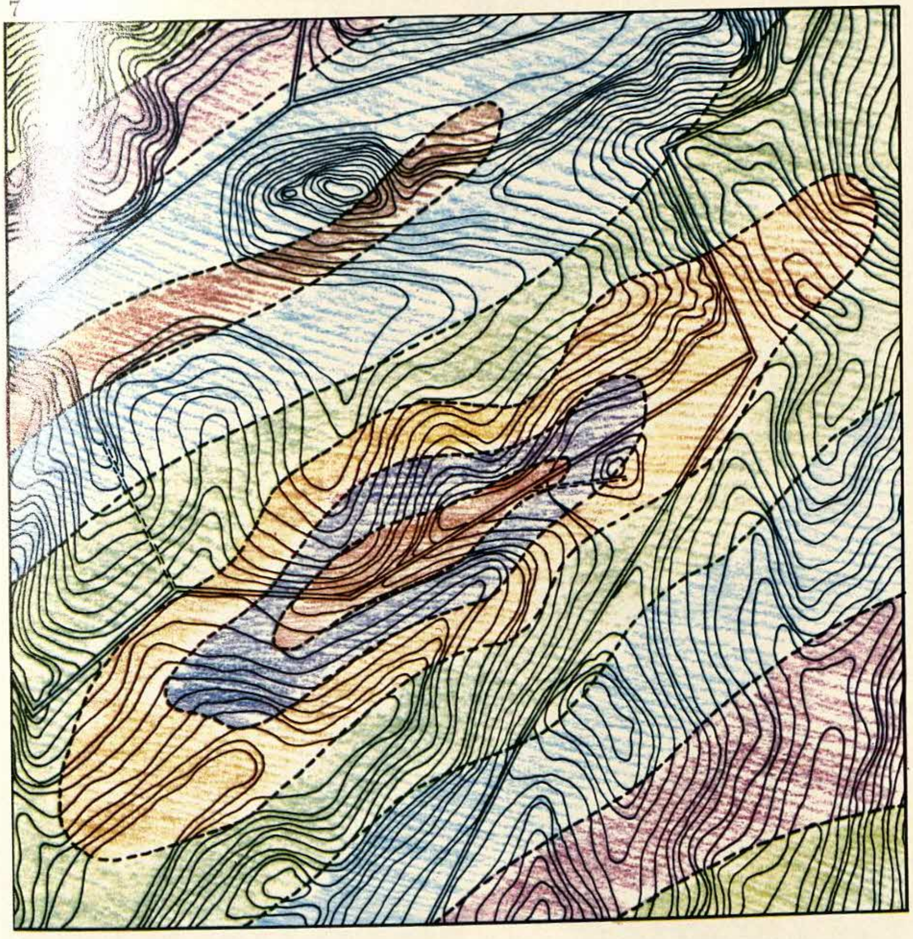

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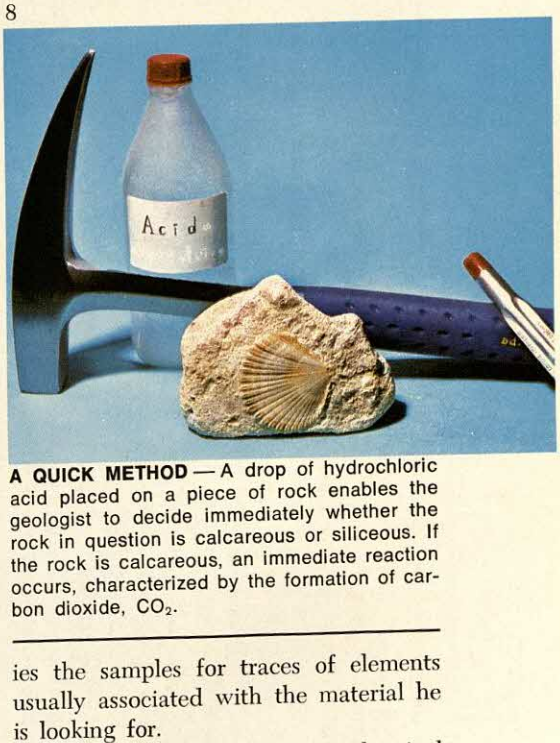

A QUICK METHOD — A drop of hydrochloric acid placed on a piece of rock enables the geologist to decide immediately whether the rock in question is calcareous or siliceous. If the rock is calcareous, an immediate reaction occurs, characterized by the formation of carbon dioxide, CO_2.

CONTINENTAL DEPOSITS | interesting sedimentary rocks

Rocks formed on the surface of the continents constitute a very small proportion of all the rocks of the Earth's crust. In fact, over 99 percent of all rocks have had their origins underground or under the seas.

Rocks are classified according to their origins as igneous, sedimentary, and metamorphic. Igneous rocks have been formed by the solidification of magma, molten material originating deep within the Earth. This magma flowed upward and often spilled out onto the surface, where it cooled and solidified as lava. Some of the magma did not reach the surface, but cooled slowly underground to form great plutonic masses. About 95 percent of the rocks of the crust are of igneous origins.

Sedimentary rocks have been formed from the fragments of older rocks, and metamorphic rocks have been formed

1

CONGLOMERATES—Conglomerates are sedimentary rocks formed by the cementing together of rounded pebbles or gravel particles. Some conglomerates consist chiefly of pebbles of one kind of rock, such as quartz or chert. Others consist of fragments of many different kinds of rocks. The pebbles in a conglomerate reveal a great deal about the history of that particular rock.

Illustration 1a shows a cross section of a conglomerate from Lombardy, in Italy. This particular kind of conglomerate is called *ceppo*, a name derived from a word in a local Italian dialect meaning "rock." The fragments constituting this conglomerate, after having been detached from the sides of mountains by fluvial or glacial erosion, rolled about in riverbeds for a long time, thus acquiring their smooth, rounded characteristics. The pebbles consist mostly of calcareous rocks, and they have been bonded together by a calcareous type of cement. Therefore, this ceppo is a rather homogeneous kind of conglomerate.

Illustration 1b shows a cross section of a polychrome conglomerate from the province of Bergamo in Italy. This rock had a fluvial origin also; that is, the pebbles comprising the conglomerate collected in riverbeds, where they were tumbled along by the current. For the most part, the pebbles are much more rounded than those in the Lombardy ceppo. Moreover, the pebbles are representative of many different kinds of rock, including limestone, marl, sandstone, serpentine, schist, and rocks of volcanic origin.

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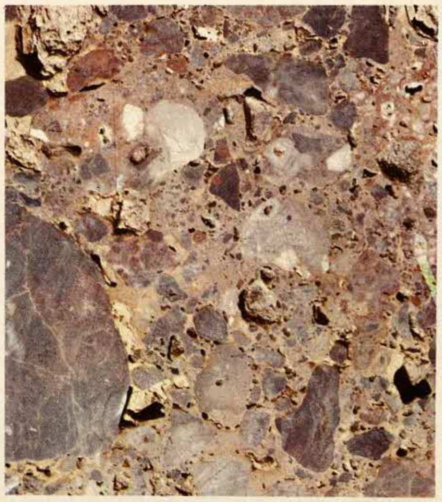

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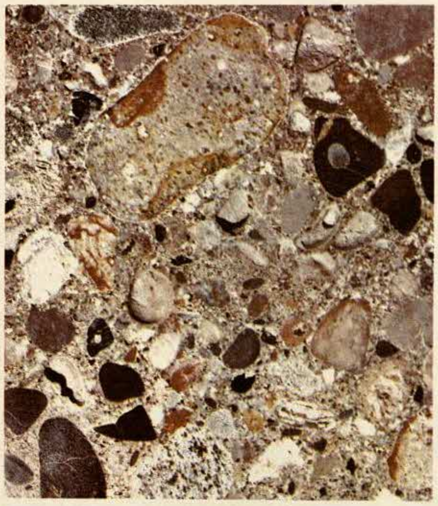

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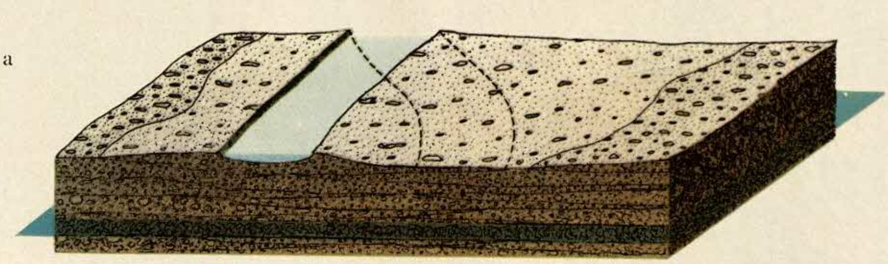

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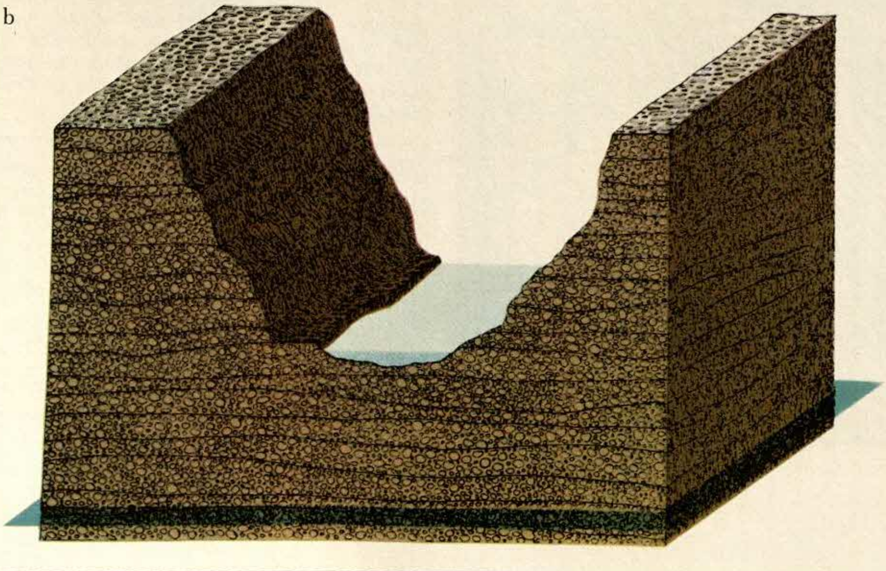


THE ORIGIN OF CEPPO—Following the end of the great Alpine orogenesis, a colossal mass of sediments (in the forms of sands and gravels) accumulated at the foot of the Alps; these materials were the products of glacial erosion and the successive destruction of glacial moraines. Rivers originating in the Alps rushed down the mountain valleys and over these deposits, carrying the detritus farther downstream. As the streams entered the great Po Valley, they began to meander across the plains. Because the waters moved more slowly than before, quantities of gravel settled out and accumulated. During periods of flood, enormous quantities of gravel were deposited by these rivers as they meandered across the plains.

When a riverbed was filled (Illustration 2a), a flood more violent than usual caused the waters to overflow and occupy a depression near the stream (shown at the right of the stream). Gravel deposited by the floodwaters gradually raised the level of the plain in this way.

Illustration 2b depicts a concomitant phenomenon: A phase of Alpine orogenesis produced a modest rise in the ground level—a rise ranging from 10 to 100 m (about 33 to 330 ft). Rivers flowing through the Po Valley reacted to the rise of the plains by accelerating their flow. They were transformed from depositors into excavators, carving out canyons in the foothills of the Alps. The walls of these canyons consisted of ceppo-like conglomerates.

through the alteration of pre-existing rocks by heat, pressure, and other factors. From the standpoint of historical geology and paleontology, the sedimentary rocks are most important.

Orogenesis, weathering, and erosion are processes that have played important roles in the formation of sedimentary rocks. Through the process of orogenesis, huge portions of the Earth's crust have been uplifted, where they have been subjected to destruction by air and water. As a result of this weathering, the rocks have gradually disintegrated; then the agents of erosion have transported the debris to the seas, depositing it on the floors of the continental shelves. In time, these sediments were transformed into sedimentary rocks. A very small proportion of the products of erosion has been deposited on land, but these continental deposits are of great interest because they reveal much about the surfaces of the continents during the various geological periods and because they permit scientists to interpret various kinds of phenomena that occur on the land surfaces today.

The phenomena of erosion and sedimentation are quite variable, and numerous factors determine the composition of sedimentary rocks. Scientists are able to determine from their study of a rock whether the fragments or sediments comprising the rock were transported for long or short distances from their places of origin, whether or not the original rocks had already been metamorphosed, and by what agent the sediment was transported and deposited.

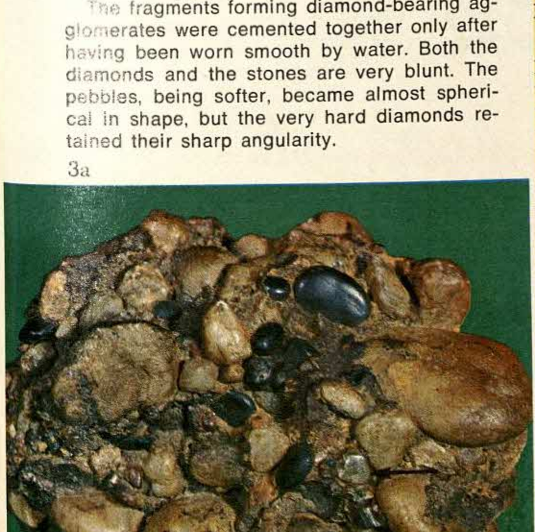
Sedimentary rocks often contain interesting and useful materials. Most mines of useful elements are found in sedimentary rocks; many are found in the areas where continental sediments have accumulated. Some continental sedimentary rocks are of poor quality, but others, if cut and polished, make beautiful ornamental stones. Moreover, sedimentary rocks often contain fossils of plants and animals that lived during periods, epochs, and ages of the past; these remains constitute the major source of information about the history of life on the Earth.

AN EXCEPTIONAL AGGLOMERATE—Agglomerate is another kind of sedimentary rock formed on continents. It is similar to conglomerate except that its constituent fragments are typically angular and of volcanic origin. Whereas Lombardy ceppo is not more than a million years old, this volcanic agglomerate from Africa (Illustration 3a) is much more ancient. The discovery of a diamond among the fragments comprising this rock indicates that the agglomerate was formed on a diamantiferous placer.

Illustration 3b shows how this agglomerate originated. At one time a large volcano rose out of the plain. Lava solidified in the deep part of the funnel-shaped throat, and the carbon separated out in the form of diamonds. After a long geological history, the volcanic cone was completely eroded. During this long span of time, the agents of erosion cut through the diamond-bearing pipe and carried the diamonds and other rock fragments to lower elevations, where they accumulated as placer deposits. In certain cases, the diamonds were mixed with sand, gravel, and other materials to form incoherent sediments. Many placers in India, Australia, Brazil, and South America are of this type.

The fragments forming diamond-bearing agglomerates were cemented together only after having been worn smooth by water. Both the diamonds and the stones are very blunt. The pebbles, being softer, became almost spherical in shape, but the very hard diamonds retained their sharp angularity.

3a



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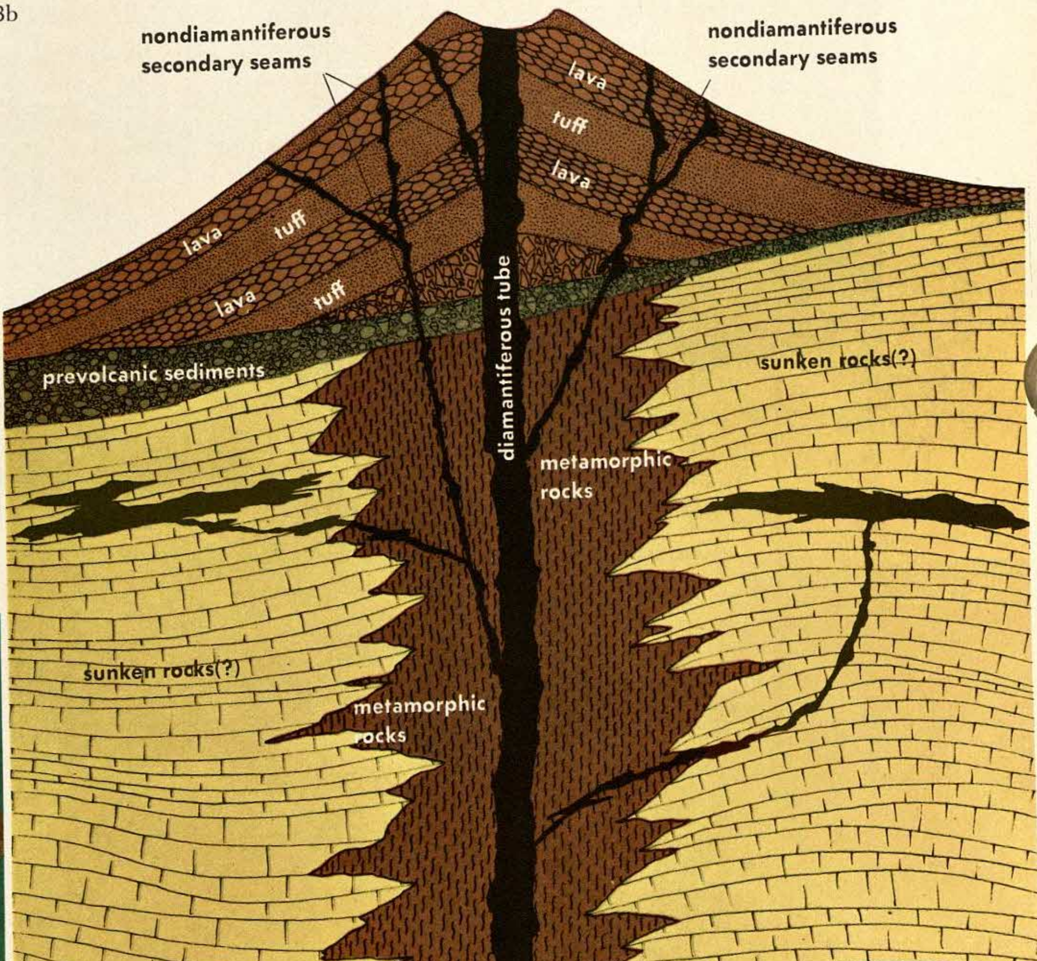

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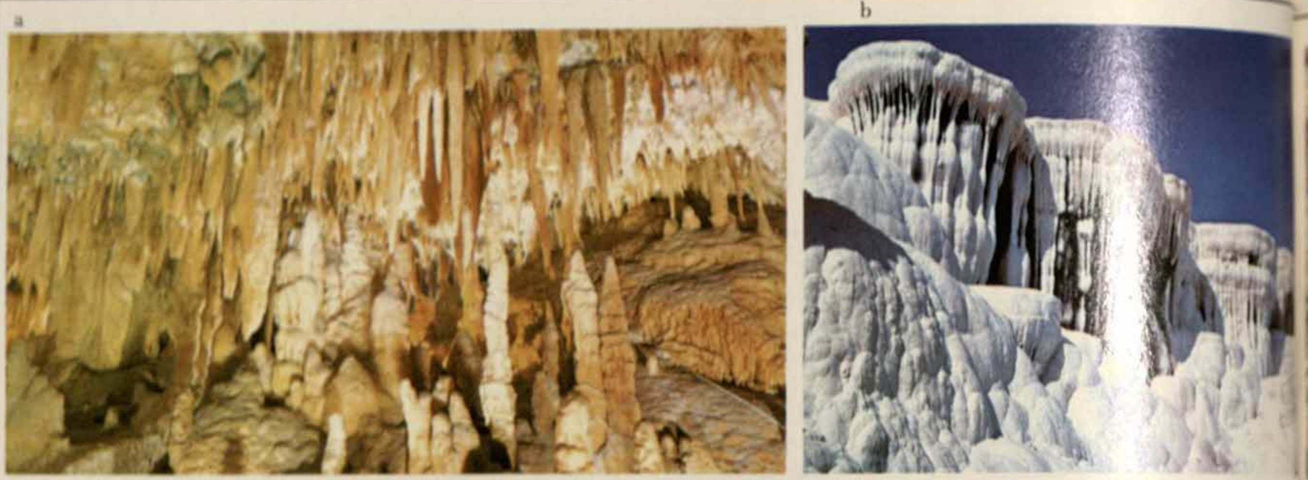

CALCAREOUS DEPOSITS FORMED BY WATER—Water seeping through calcareous rocks may become enriched with calcium carbonate, which may later be deposited as stalactites, stalagmites, and other formations in caves and caverns.

Illustration 4a shows some of the gorgeous stalactites and stalagmites in the grotto of Castellana in Italy. In the United States, similar spectacular formations may be observed in Mammoth Cave in Kentucky, Luray Cavern in Virginia, Carlsbad Caverns in New Mexico, and other famous caves.

The deposition of so-called dripstone materials ordinarily occurs in caves, caverns, and grottoes, but under certain conditions a similar phenomenon may occur on the Earth's surface. For example (Illustration 4b) at Punakkale, near Denizili, Turkey, springs rich in calcareous substances come to the surface, leaving large concretions and forming beautiful, gigantic terraces.

Illustration 4c shows a portion of a travertine deposit, which is found in central Italy where

THE ORIGINS OF CALCAREOUS ONYX AND TRAVERTINE—This geologic profile shows two ways in which rocks such as alabaster and travertine can originate. On the left, surface water penetrates deep into calcareous rocks; inasmuch as the temperature increases with depth, these waters are heated, thereby increasing their ability to dissolve the rocks through which they pass. As these waters cool they tend to precipitate out the dissolved materials and form concretions either in caverns or on the surface. Surface waters penetrating rocks in the vicinity of a cooling pluton (shown in red) are heated to very high temperatures. These waters carry rich loads of carbonates,

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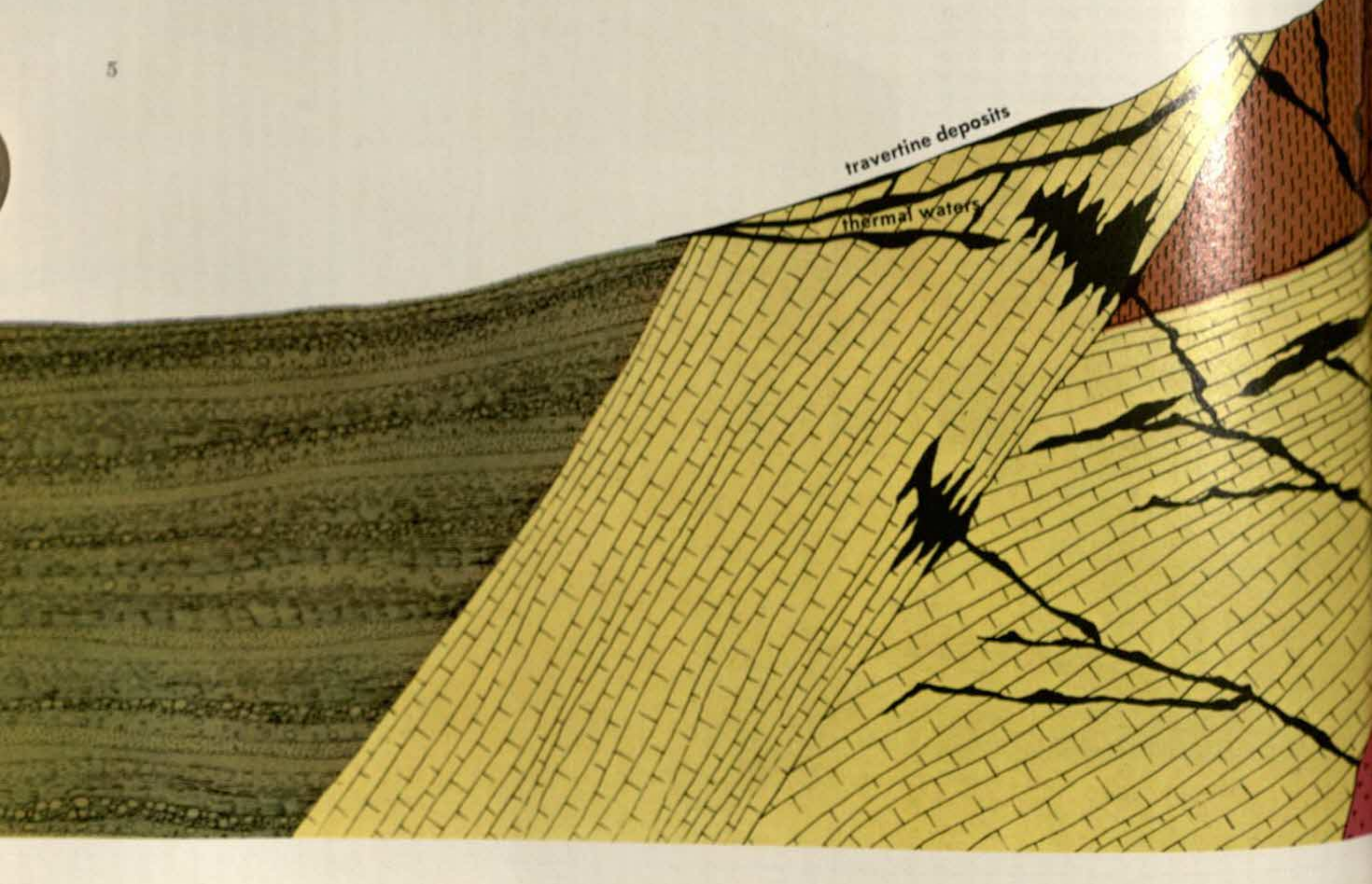
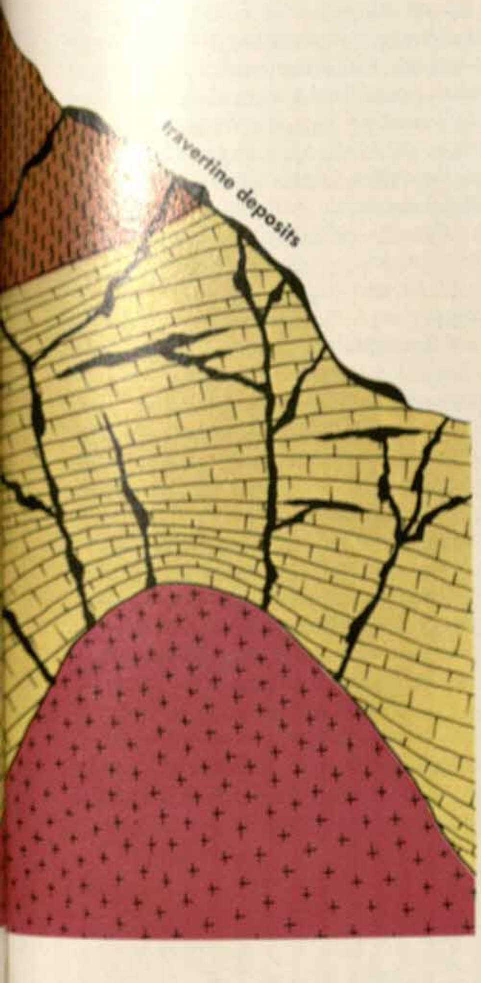


c

springwaters of volcanic origin are common. The hot waters of the springs dissolve great quantities of calcium carbonate, and these materials are precipitated out as the waters cool, usually as they flow over the floors of caves or over the surface of the land. Very often travertine contains some very interesting fossils of plants and animals.

which are deposited when the waters gush out on the surface as hot springs. Such is the origin of the travertines that are abundant in the [illegible] Valley in Italy.



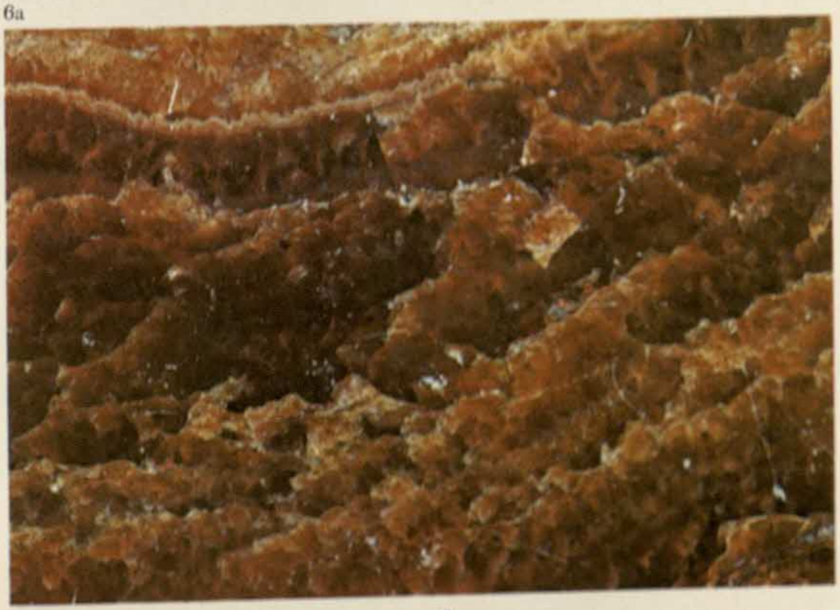
ROCKS WITH CHEMICAL ORIGIN—Often when water passes over two rocks that are in contact with each other, changes resulting from chemical interaction occur. The altered substances may be soluble, and they may accumulate locally over a certain distance, forming rocky veins or strata. Such rocks, especially if they have been produced by the action of thermal waters, may be quite pure and useful as ornamental stones or building materials.

Illustration 6a shows a translucent slab of calcareous alabaster; the reddish color is due to iron-oxide impurities in the rock. The accumulation of layers, one on another, and the formation of crystals of relatively large size indicate that this rock has not undergone complicated geologic and thermal transformations.

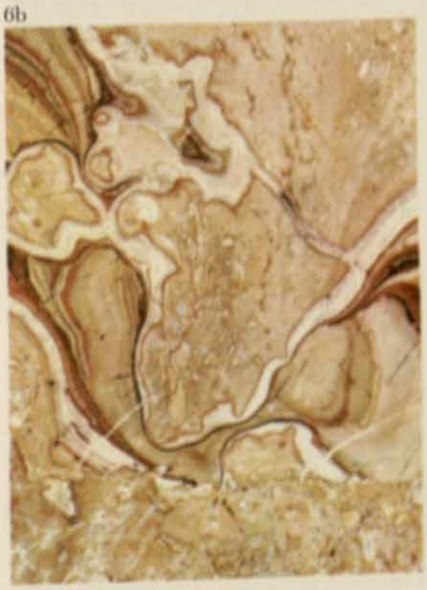
Illustration 6b shows a polished slab of alabaster, a rock composed of calcium sulfate, deposited in uniform layers. The fracturing of these layers produced a breccia, which was again permeated with waters possessing a high calcium sufate content. These waters not only filled the spaces between the breccia, but also partially dissolved and rounded the edges of the sharp fragments.

Illustration 6c shows veins of potassium salts in a mine. These salts are excavated for use as industrial raw materials.

6a



6b



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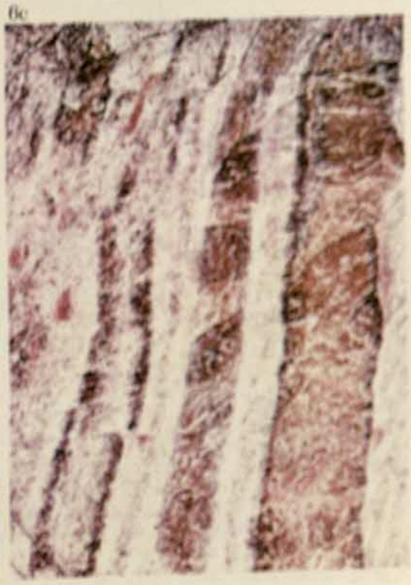


ATMOSPHERIC ELECTRICITY

an electromagnetic storm

ELECTRICITY

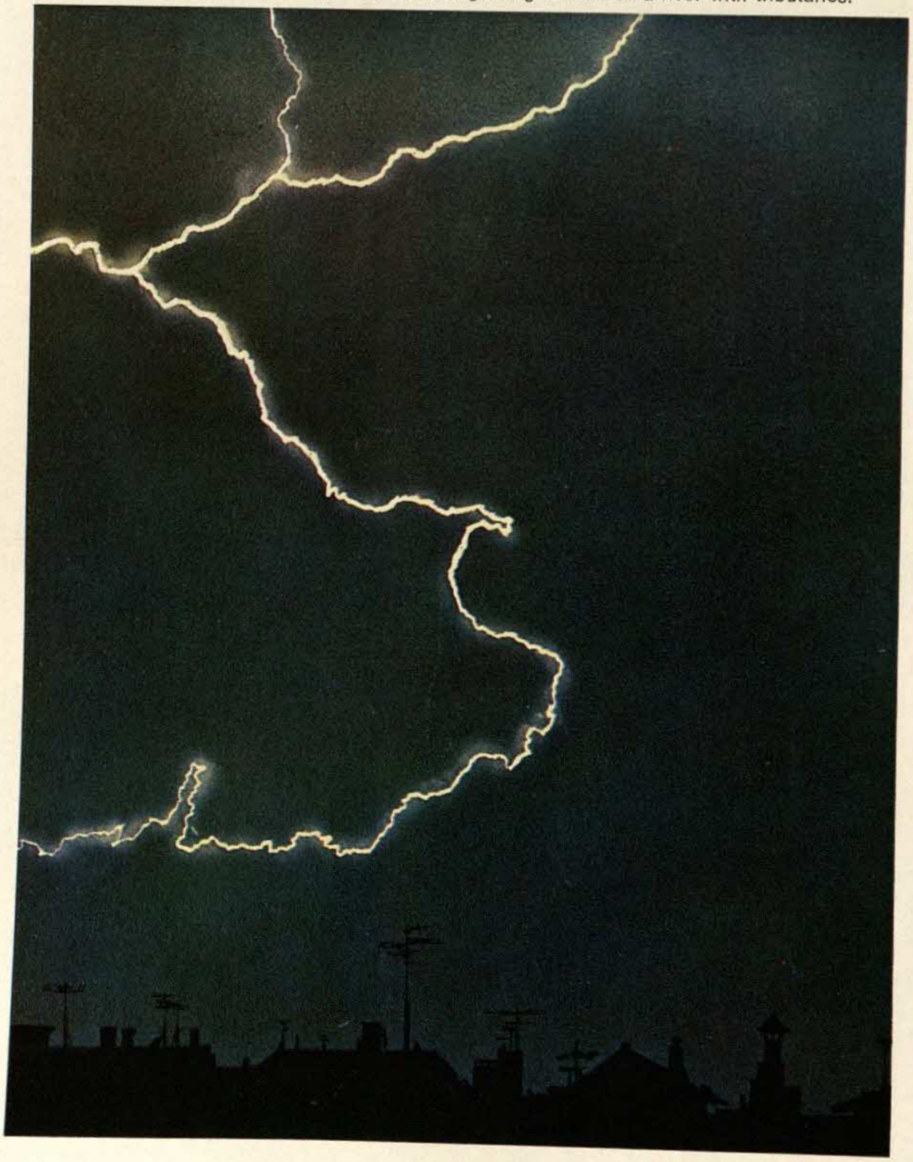
A thunderstorm is an awe-inspiring phenomenon, with its brilliant flashes of lightning and its loud crashes and rumblings. Speculations about the power and destructive force of lightning live on in the folklore of every land.

WHAT IS LIGHTNING?

Lightning is an electrical discharge, a colossal spark that jumps between one cloud and another or between a cloud and the Earth. A lightning bolt has a characteristic jagged shape, sometimes with offshoots similar to the tributaries of a river. Lightning is extremely bright, usually yellow in appearance, but sometimes violet.

When lightning is hidden from view by clouds, the clouds may appear to be uniformly illuminated. At night, lightning from a distant storm may light up the horizon while the sky above remains starry and calm.

BRANCHED LIGHTNING—The pattern of this lightning resembles a river with tributaries.



THE BRANCHED SHAPE

Lightning jumps between a part of a cloud having one electrical charge and the ground or another part of the cloud having the opposite charge. The electrical charge of a cloud is the sum of all the charges of the droplets of water of which the cloud is composed. As these minute charges leap toward an opposite charge, they flow together. A lightning bolt is a kind of canal through which electrical charges flow to an opposite pole; its branches are smaller canals that collect the charges.

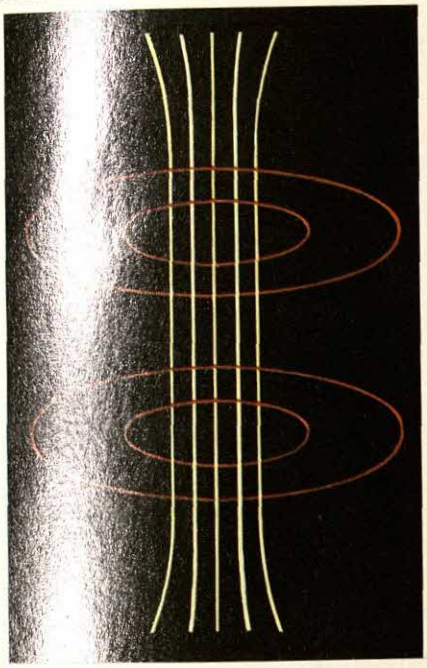
THE JAGGED SHAPE

The path of a lightning bolt is composed of atoms of oxygen, nitrogen, argon, and other elements that, struck by electrons, carry the electrical charge from one pole to the other. As these atoms are struck violently by the electrons traveling at several kilometers or several tens of kilometers per second, they in turn lose their electrons, becoming ions (atoms that have lost or gained at least one electron). These ions combine immediately with the electrons of the electrical discharge, and this is the origin of the intense light of the lightning bolt.

Thus the lightning bolt is an electrical current flowing through a gas (the air) rather than along a conductor such as copper wire. An electrical current flowing through a gas under these conditions changes direction continually as it follows the path of least resistance. However, when these detours carry the discharge too far from the direction of the opposite pole, the path returns to its proper direction.

Another reason for the irregular path of the electrical discharge is that, because it is an electrical current, it generates a magnetic field around itself. The field may accentuate the changes in direction of the discharge. This magnetic field actually contains the discharge within a narrow area varying between several centimeters and several decimeters; otherwise, the discharge might spread out into space.

THE MAGNETIC FIELD OF LIGHTNING—A lightning bolt creates a magnetic field (red circles) that keeps the electrical discharge within a certain thickness.



THE COLOR OF LIGHTNING

The flash of lightning is due primarily to the light emitted at the moment at which the ions, capturing the necessary electrons from the discharge, return to their normal state as atoms. However, a part of the light is also produced by the collision of electrons with the ions or with one another. These are the phenomena that produce the characteristic yellow light.

FORKED LIGHTNING—In the United States, this kind of lightning is responsible for one death and four injuries every day. One branch usually becomes the main discharge channel.

OSCILLATING LIGHTNING

Lightning flashes may occur repeatedly along the same path or nearly the same path at very frequent intervals. Because lightning consists of an electrical current, the two poles between which it flows are oppositely charged. For example, the current might carry a positive charge from one cloud to another cloud that is negatively charged. It may happen that the lightning carries an excess charge and that after the flash the two clouds are once again charged, but oppositely to the charges they carried before. Under these conditions another discharge may occur; this too may reverse the polarity of the two clouds, causing a third discharge that may in turn cause a fourth, and so forth. The discharges follow one another at intervals of perhaps a few tenths or a few hundredths of a second. The phenomenon is analogous to that produced in the laboratory when a spark is made to jump between two poles of a charged condenser.

THE EMISSION OF RADIOWAVES

The discharge of lightning creates an intense electrical current in space, and around this current a magnetic field is generated. The field expands in space in the form of electromagnetic waves of the frequency range of radio receivers, causing a blast of static over most of the long-wave bands. Sometimes long-range radiowaves meet atmospheric disturbances generating such strong magnetic fields that the waves themselves are changed, making the transmission unintelligible.

VOLTAGE, AMPERAGE, WATTAGE, AND KILOWATT HOURS OF LIGHTNING

A lightning bolt running from a low cloud to the Earth may be a few hundred meters or a kilometer in length;

lightning between two distant clouds may run along a path as long as 15 km (about 9 mi). By approximating the distance that lightning travels, the difference in potential that caused it can be computed. About a million volts are required to cause a spark to jump between two electrodes only 1 m (about 3 ft) apart. Thus lightning traveling a distance of 1 km (about 0.6 mi) is caused by a difference in potential of about 1 billion volts; a lightning bolt 5 km (about 3 mi) long shows a difference of potential between the two poles of about 5 billion volts.

The rate of current flow in a lightning bolt may be as much as 1,000 amperes (a home washing machine requires about 10 amperes). The power needed to create a lightning bolt can be computed by multiplying amperes by volts.

The power of a lightning bolt 1 km long is very great, perhaps as much as 1 billion watts, a million kilowatts—that is, for an instant, many times the power of an average size hydroelectric plant or a thousand times the power of a large atomic power plant. This impressive power only lasts for about one thousandth of a second.

The total energy of a lightning flash can be computed by multiplying the power by the time of its duration.

THUNDER AND THE MECHANICAL EFFECTS OF LIGHTNING

A flash of lightning is followed by a clap of thunder. The heat and light of the discharge cause the cylinder of air around it to expand rapidly, producing sound waves that can be heard at a great distance.

Sound waves travel at a speed of about 331 m/sec (about 1,086 ft/sec), so it is possible to compute the distance from the point of observation to the place where lightning strikes by counting the seconds between the flash of light and the sound of thunder. Each second indicates slightly over 300 m (about 1,000 ft) of distance.

If lightning strikes a solid object, it can cause an explosion. When it strikes a tree the tree may be split in two; the trunk seems to have exploded at the point where the lightning struck. This is because the strong electrical current can instantly vaporize the liquids contained in the trunk, causing the air in the pores of the trunk to expand. The increased volume of these gases causes the trunk to break.

WHERE LIGHTNING STRIKES

Unfortunately, many people still put stock in the old and erroneous notion that lightning never strikes twice in the same place. Indeed, some individuals have lost their lives by seeking shelter in or near a place where lightning had struck previously.

This superstition is but one of many unfounded beliefs held by people in various parts of the world. In Germany, for example, an old folk verse issues this warning: "Beware of an oak: it draws the stroke; avoid an ash; it courts the flash. . . ." According to other superstitions the poplar, walnut, and locust are trees that attract lightning, and the aspen, bay, beech, elder, hawthorn, laurel, and certain other trees are supposed to repel lightning. Cats, dogs, horses, and mules are said to attract lightning; bell, book (the Bible), and candle, on the other hand, are considered helpful in averting or abating lightning. In view of current knowledge, none of these notions has any foundation in fact.

Where lightning strikes actually is not totally a matter of chance; rather, it is in accord with two general rules. Lightning tends to strike high pointed objects and objects from which hot gas or air is rising. Columns of hot air contain a certain number of ions and are, therefore, electrical conductors that channel the lightning to the ground.

Therefore, trees and tall pointed buildings attract lightning and are not desirable shelters during a storm. The hot smoke from a chimney, and even the hot air rising from a flock of sheep that have stopped to await the end of the rain may attract lightning.

FOLKLORE AND SUPERSTITION

The superstitions mentioned in the preceding section are but a few of the erroneous beliefs concerning lightning, beliefs that persist in the world today. In the United States, for example, a common folk belief holds that fires started by lightning can be extinguished with milk only. In many places the wood of a tree struck by lightning is considered to have magical or curative properties. Such beliefs are totally without foundation.

The origins of superstitions are often found in the dim past, when knowledge of natural phenomena was either very limited or nonexistent. In many ancient religions, the gods were believed to manifest themselves through lightning and thunder. Before the electrical nature of lightning was discovered, the thunderbolt (lightning bolt) was considered the weapon of the god Zeus in Greek mythology. Jupiter (in the Roman mythology) and Thor (in the Teutonic mythology) were counterparts of Zeus; other mythologies of antiquity also had their own storm gods. In parts of southeast Asia and China today, people believe that thunder, lightning, rain, and fertility fall under the sacred control of dragons.

Speculations concerning the power of lightning have not been limited to primitive peoples or to the great mythologies of the world. The folklore of many lands abounds with ideas that have emerged principally from the Judeo-Christian tradition. Among the Jews in Old Testament times lightning was regarded as evidence of the divine will of Yahweh (Jehovah); consequently, it struck fear in the hearts of the people. Even today death and destruction by lightning are considered by many to be acts of God; thus the ancient idea persists. Among Negroes of the African Gold Coast, for example, the belief that lightning is a manifestation of divine will prevents the people from extinguishing fires started by lightning and from rendering aid to any individual struck by lightning.

In Christian communities, certain kinds of transgressions are believed to be punished by lightning; perjury, blasphemy, desecration of holy places, and profanation of the Sabbath are among the kinds of sins that are frequently cited as meriting punishment by lightning.

As scientists learn more and more about lightning and other natural phenomena, and as people in general become better informed about the happenings in the world around them, faith in superstitions tends to diminish.

ATMOSPHERIC DUST | impuritics in the air

Although brilliant colors of the rising and setting sun have inspired many poetic thoughts, these colors actually have a rather inglorious origin. They are caused by fine dust suspended in the lower levels of the atmosphere. Just as the waters of a river or a lake contain minute particles of sand, clay, and vegetable matter, the atmosphere holds various particles in suspension—particles that mostly are considerably smaller than those suspended in water. These particles are responsible for many recognizable phenomena.

OBSERVING ATMOSPHERIC DUST

Even on a very calm day, clear air holds particles of solid material in suspension. Although it is not possible to see them, it is possible to discern their presence. For example, from an altitude of about 3,000 m (about 10,000 ft) objects on the ground appear less distinct the farther away they are—as if wrapped in a haze. The haze appears only below the point of observation; above, the sky is clear. On the horizon the color of the sky would clearly contrast with the beige of the haze below. This beige color is similar to the light beige-brown of silt suspended in water.

THE LIMITS OF ATMOSPHERIC PARTICLES

Atmospheric dust is generally found under a certain altitude, about 3,000 m, because only the air at lower altitudes is dense enough to hold the dust in suspension. Thus, even if particles do reach the higher atmosphere, the larger ones quickly drop to a lower level, especially when there are no updrafts. The upper atmosphere is almost completely free of dust.

Where there is no dust the air is exceptionally clear, and the sharp images of distant objects create the illusion that they are closer than they really are. For example, from atop a very high mountain on a clear day, it is impossible to estimate accurately the distance to other very high mountains, which seem very close because of the limpidity of the air.

THE COMPOSITION OF ATMOSPHERIC DUST

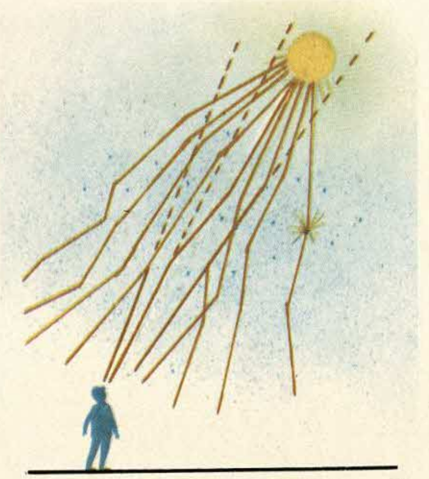
To know the exact composition of atmospheric dust, it would be necessary to gather and analyze all the particles—large, small, and extremely minute—suspended in the air, a procedure obviously impossible. Nevertheless, some quite efficient methods of study have been developed. One of these consists in directing the flow of air between two poles having opposite electrical charges. An electric field is created between the two poles and the dust is attracted by the electrical force toward an adhesive tape attached to one of the poles. The air is driven past very slowly by a fan, and the particles are collected on the sticky tape. These particles are then examined under a microscope.

Many sources contribute to the formation of atmospheric dust. These are some of the most important:

1. dust raised from the desert by the wind;
2. dust from volcanic eruption;
3. dust raised from the ground by the wind;
4. salt from sea spray that evaporates before it can fall back into the ocean;
5. dust from disintegrated meteorites;
6. pollen from plants;
7. man-produced dust.

THE DIFFUSION OF SUNLIGHT

Light striking a particle of atmospheric dust is diffused. On a clear day an observer standing in the shadow of a telephone pole will note a luminous halo around the pole. This is because some of the sun's rays passing through the atmosphere strike the particles in the air and are deflected. For this reason such rays seem to come from the area around the sun rather than directly from the solar disk.



DEFLECTION OF THE SUN'S RAYS—The sun's rays are deflected as they pass through the atmosphere; thus some of them seem to come from an area (indicated by broken lines) outside the solar disk.

Repeating the observation at an altitude of 2,000 or 3,000 m (about 6,500 to 10,000 ft) would show that the brightness of the sky around the solar disk is diminished considerably. As the altitude is increased the brightness of the sky lessens; outside the atmosphere it disappears entirely.

A coronagraph—a telescope equipped with a circular diaphragm that occults the image of the solar disk—allows observation of the sun's corona, the highest part of the sun's atmosphere. The light of the corona is very weak—about one four-hundred-thousandth of the light emitted by the solar disk, equal to the light reflected by the full moon. Such observation is possible only if the instrument is located above the atmospheric dust; that is, at an altitude of at least 3,000 m (about 10,000 ft) above sea level. At a lower altitude the weak light of the corona is darkened by the light diffused by particles in the atmosphere.

ARTIFICIAL SUNSET

At night, an interesting sight can be seen at a distance of 20 to 30 km (about 12 to 19 mi) from a large city. Although there are no signs of houses or lights in the direction of the city, all that part of the horizon will be aglow. This is because the light from the city is diffused by the particles of moisture and dust in the atmosphere above. The natural dust above large cities is often permeated with particles from man's activities, a phenomenon better known as air pollution.

POLLUTED AIR

All of the major cities of the world have been plagued with an increasing load of pollutants in the air. The air quality in such industrialized and motorized cities as New York, Chicago, Los Angeles, London, and Tokyo has become seriously affected by smoke from burning solid fuel and trash, by carbon monoxide and hydrocarbons, and by oxides of nitrogen and sulfur from a variety of industrial sources.

Automobile tires grind into the pavement and are slowly pulverized into colloidal material, and the development of efficient braking systems for automobiles has led to the release into the air of material that contains toxic asbestos particles. City air contains an immense variety of other ill-defined matter.

Quite another aspect of air pollution has been the long-term effect on the climate of the world as a result of changes in the atmospheric composition. Carbon dioxide, a major product of the combustion of fuels such as coal and petroleum products, has been gradually increasing as a constituent of the Earth's atmosphere since about 1920. Part of the additional tonnage of carbon dioxide stays in the atmosphere, part goes into the oceans, and part is incorporated into living organisms. The net result has been a rise of about 0.2 percent per year in atmospheric carbon dioxide. Theoretically, this increase should cause a small rise in the mean surface temperature of the Earth over a period of decades.

The mean temperature of the world did rise by about half a degree centigrade between 1880 and 1940, but since then it has decreased slightly, possibly because of more haze.

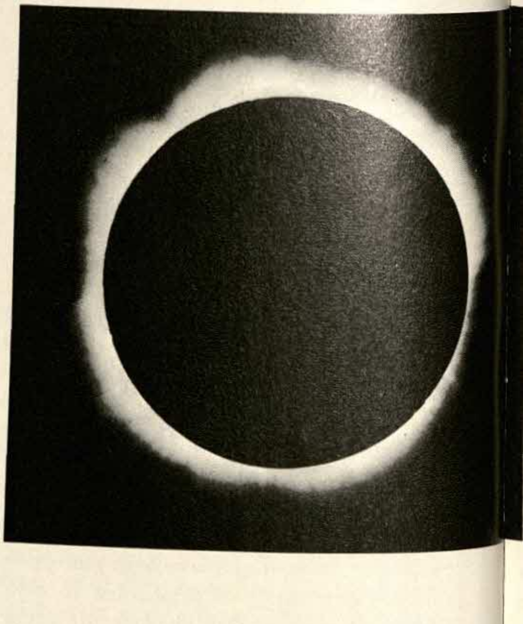
THE COLOR OF THE SUNSET

Cigarette smoke appears light blue in sunlight or in the light of a lamp. If cigarette smoke is blown into a tube about 50 cm (about 20 in.) long and observed against the light, however, it will appear to be yellow-orange. The smoke is made up of minute particles about the same size as the particles in the atmosphere.

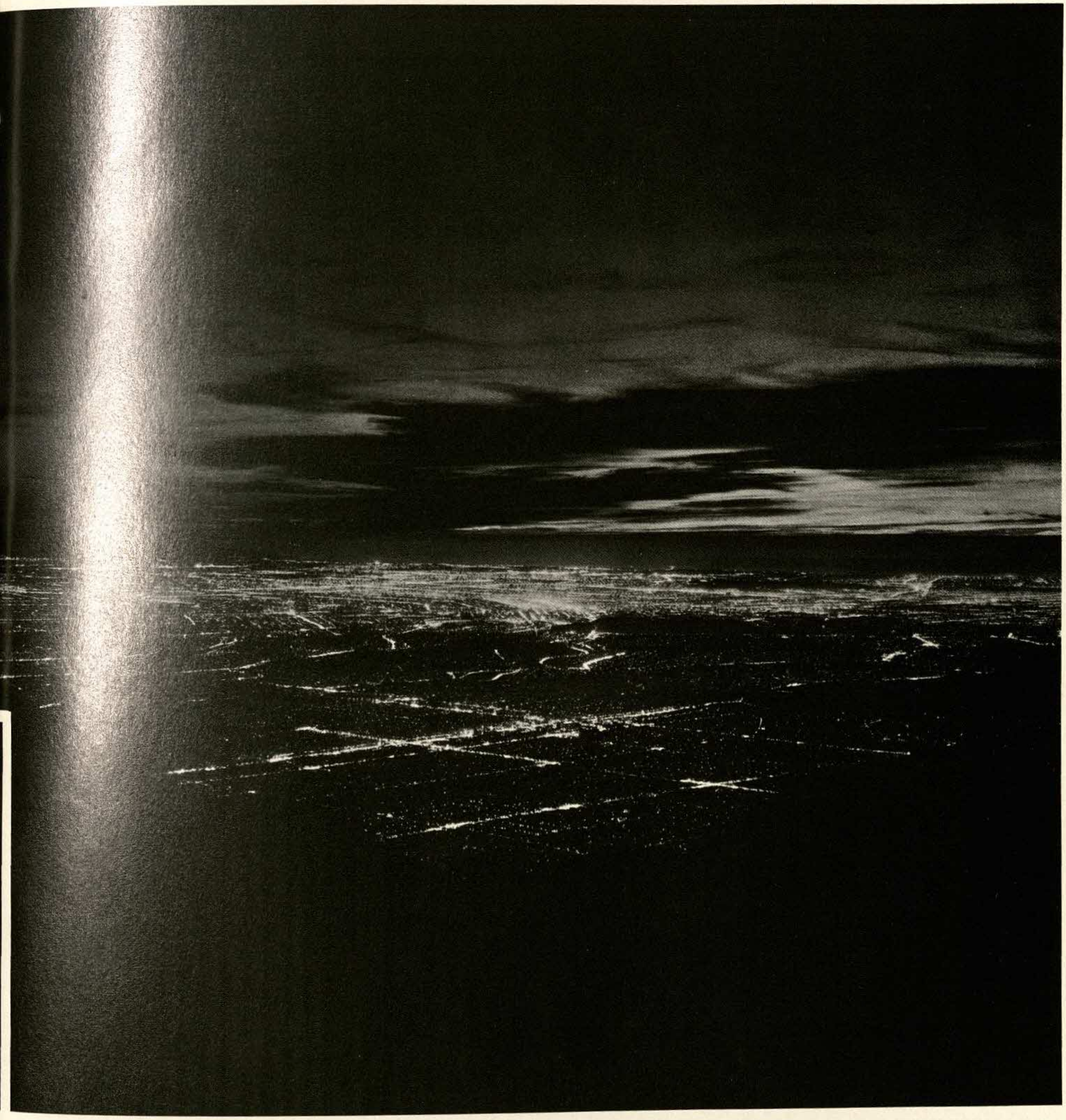
Rays of light striking dust particles are diffused. If the particles are very small—equal to the length of the light wave or about 0.0005 mm—blue and violet light will be diffused much more readily than yellow, orange, and red light. The diffusion of violet light is about sixteen times stronger than the diffusion of red light. Therefore, when a ray of light passes through air filled with fine particles, its light is broken up into its component colors; red, orange, and yellow pass through the particle-filled air fairly easily, but blue and violet are diffused in all directions. For this reason, a puff of smoke appears bluish when seen from the side from which it is illuminated, because the smoke particles mainly diffuse the blue and violet light. Seen against the light, however, it looks yellow-orange, because these are the colors of light that pass most easily through the smoke particles. Light from the sun at sunset travels obliquely through about 100 km (about 62 mi) or so of air containing minute particles; because of this, the color of the light is changed. The red rays pass through most easily; orange rays are only slightly diffused; but yellow, green, blue, and violet rays are diffused to a greater extent. Therefore, the light of the sun at sunset or sunrise appears to be red and delicately tinted because lesser amounts of other colors, even of violet, are mixed with the red.

Viewed from a higher altitude where the air contains fewer atmospheric particles, the light of the sunset appears less red because it has lost less of its blue and violet colors, which have not been absorbed as they would be at a lower altitude.

LIGHT DIFFUSION OVER LOS ANGELES — This photograph, taken at night, shows the glow above the city of Los Angeles. The sky above the horizon is glowing with the lights of the city because the city light is being diffused by atmospheric dust, smoke, and water vapor.



THE SUN'S CORONA —The extremely weak light of the sun's corona is visible only through an atmosphere that is free of dust particles.



SUNSET—The rays emanating from the setting sun appear to be colored red. This is because they must pass through the Earth's atmosphere, which contains many particles. Red light passes through more quickly and easily than light of any other color.

THE CLOUDS | weather signs in the sky

Clouds are indicators of the meteorological situation developing over an area. It is often possible to forecast the weather several days in advance from the appearance and nature of clouds.

The person who recognizes summer thunderclouds knows when to carry an umbrella. Precipitation in significant amounts usually falls from only a few kinds of clouds: altostratus, nimbostratus, and cumulonimbus; the word *nimbus* means rain cloud. People who climb mountains or go out in boats, even a short distance from shore, should be able to recognize cloud formations that indicate the approach of a sudden change in the weather. In particular, pilots of light planes need a thorough knowledge of cloud types and their significance.

The development of aviation in the early part of the century greatly stimulated the scientific study of clouds. Today, however, most commercial planes fly high above the clouds, and their pilots depend largely on weather reports, rather than the appearance of clouds, for their knowledge of winds and weather.

1

MEASURING THE CLOUD COVER—The simplest observation that can be made of clouds is measurement of the cloud cover. Sometimes the sky is perfectly clear, sometimes it is completely obscured by clouds, and sometimes it is only partially obscured. The ratio between the area covered by cloud and the clear area is the cloud cover, which is expressed as a percentage.

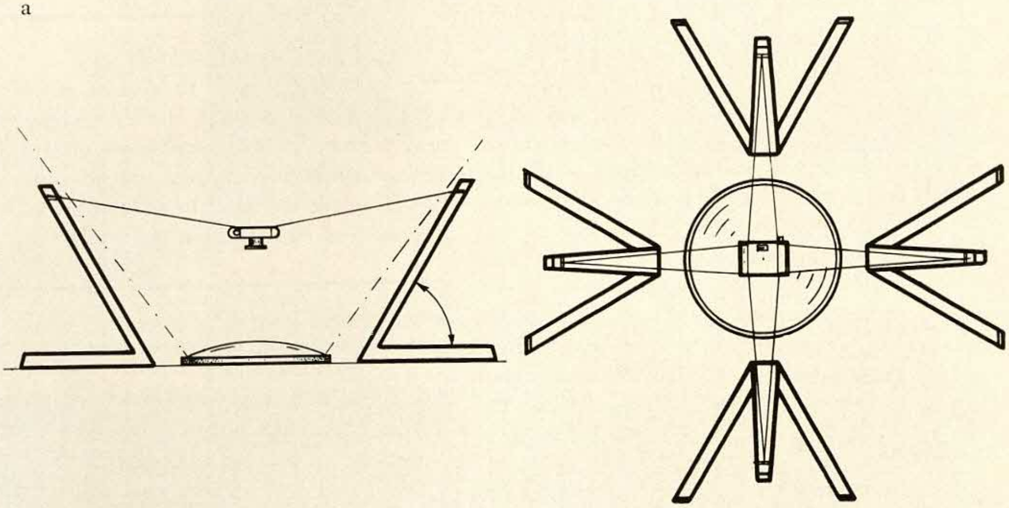
The ratio is calculated from a photograph of the sky. The photograph is enlarged and then covered with a transparent plastic sheet on which a grid of squares is marked. To determine the ratio, the observer counts the squares that are clear and the squares that are cloud-covered. A photograph used for this purpose is taken with the camera pointed toward the zenith—that is, vertically. A camera equipped with an ordinary lens will take a picture of only a small area, but this is not a great disadvantage because only the part of the sky near the zenith is considered when cloud cover is measured. If a part of the sky near the horizon was photographed, the result would be misleading because the clouds would appear close together, due to the angle from which they were photographed.

The best photograph for measuring cloud cover is one that takes in the sky within about 60° of the vertical. A wide-angle lens can be used to take this view, or the alternative method shown in Illustration 1a can be used. An ordinary camera is supended by wires from four supports so that it points toward a convex mirror mounted near ground level. Mirrors of this kind are commonly used in store surveillance, or at blind traffic intersections. The wide-angle view of the sky reflected in the mirror is photographed by the camera.

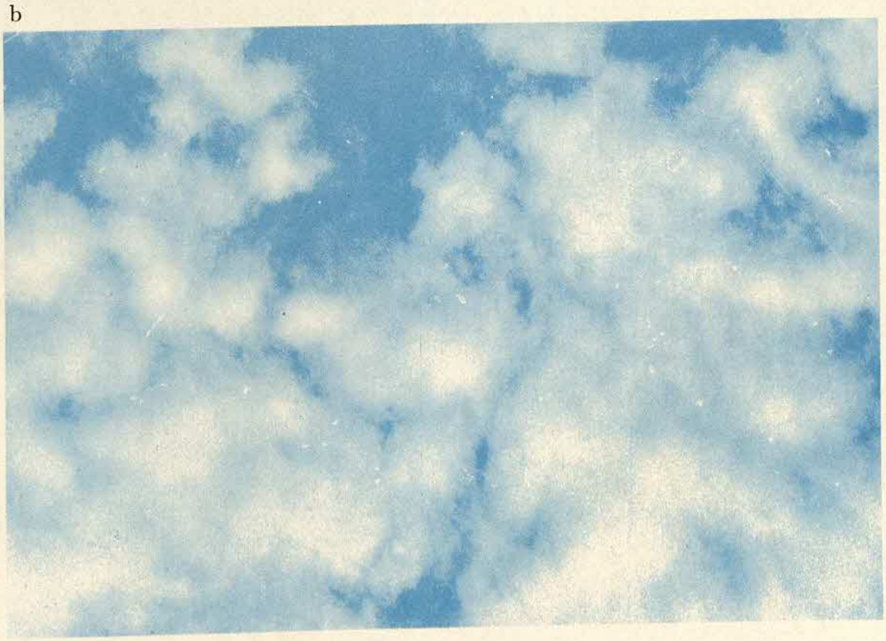
To obtain the desired field and a sharp focus, the distance between camera and mirror can be adjusted by trial and error. Sharp focus is important, as the edges of the clouds should show clearly on any photograph used for measuring cloud cover.

Black-and-white photographs are generally used for this purpose. A conscientious observer will measure the cloud cover at least once a day to make a complete record for meteorological purposes.

a



b



2

THE ADVANTAGES OF INFRARED FILM—Special films and filters can be used to obtain sharp black and white pictures of clouds, even on hazy days. One method is to use a film with infrared-sensitive emulsion, along with a deep red filter. Only infrared radiation, which passes easily through mist or haze, reaches the film and creates the photographic image. This infrared photograph shows white clouds sharply defined against a dark sky; in an ordinary photograph of the same scene the clouds would be scarcely visible.

PHOTOGRAPHING CLOUDS FROM THE EARTH

One good way to learn about clouds is to search the sky for examples of the different kinds shown in a cloud atlas and to photograph them. Cloud atlases contain pictures of many intermediate types of clouds, besides the basic types.

There are certain tricks to photographing clouds, and these are best learned through experience. An exposure meter is helpful, but the bright parts of the clouds may reflect so much light that a lens setting different from that indicated by the meter is needed if details are to show clearly in the photograph.

When photographing clouds it is not necessary to include the horizon or objects on the Earth's surface. It is important, however, for the photographer to record and indicate in some way the position of the camera, with respect to the vertical, when the picture was taken.

UNUSUAL CLOUDS

Some cloud photographs have value because of the great beauty or rarity of the cloud formations they show. A list of unusual clouds worth photographing follows:

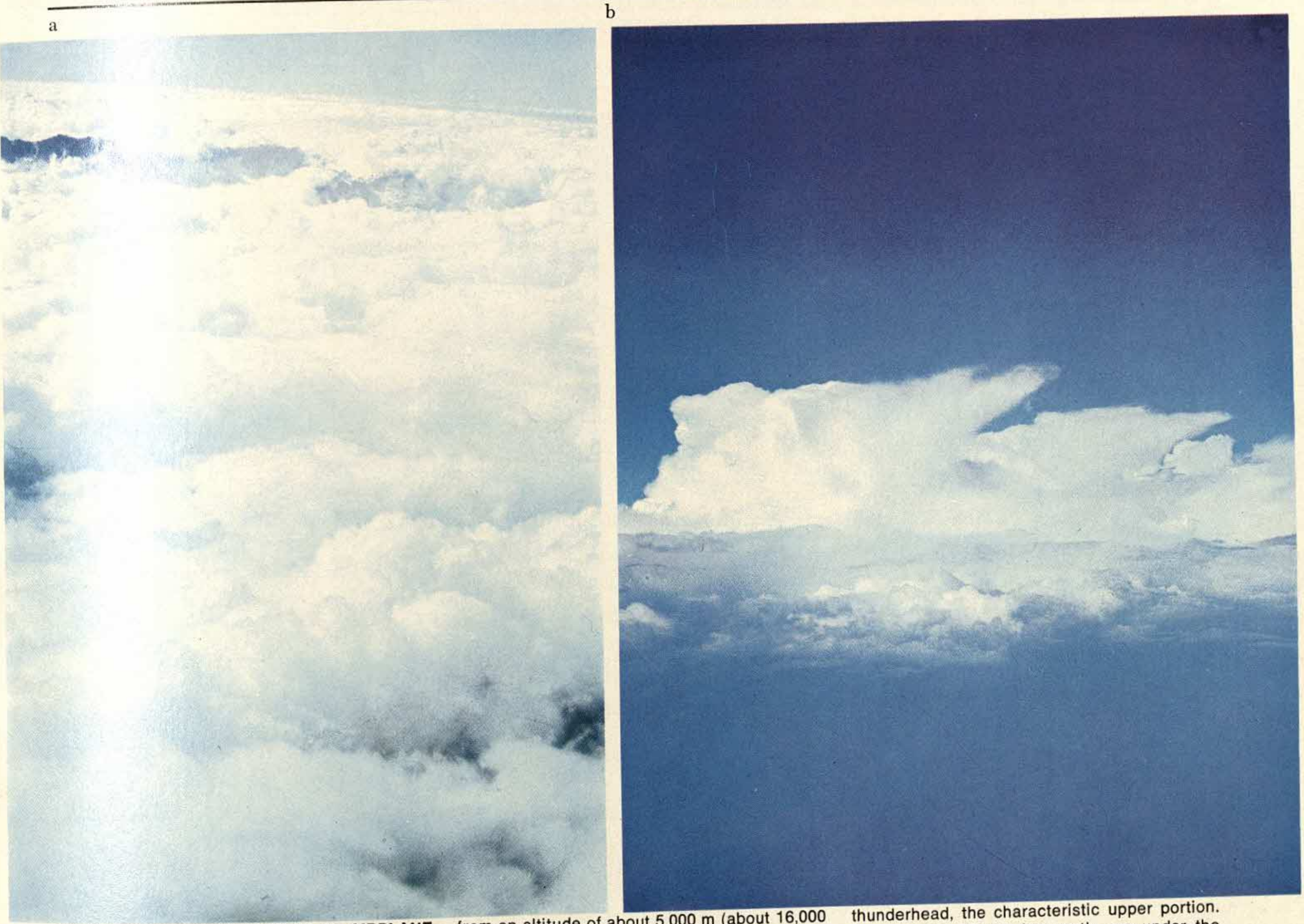
Mother-of-pearl (*nacreous*) *clouds* show an iridescent shading of faint rainbow colors. The colors are due to the refraction of sunlight by minute ice crystals in the clouds, which occur at altitudes above 25,000 m (about 85,000 ft).

Cirrus clouds around the sun or moon create a halo effect. The circle of brightness may be white or iridescent, and a second circle may appear outside the first. The halo is due to the refraction and reflection of light striking ice crystals in the cloud. Sun dogs or mock suns are concentrated points of brightness at two or four points on the halo that appear to be duplicate images of the sun itself, slightly blurred and not so bright. Sun dogs are most often seen in cold climates near the Poles at sunset.

A SEA OF FOG—This aerial photograph, taken from an altitude of about 6,000 m (about 20,000 ft), shows a vast fog bank lying close to the ground. Fog seldom produces rain or snow.

3

4



TAKING PHOTOGRAPHS FROM AN AIRPLANE—An airplane provides opportunities to take photographs of clouds from an unusual angle and to learn more about the true shapes of clouds than can be learned from the ground. For example, Illustration 4a, photographed from an altitude of about 5,000 m (about 16,000 ft), shows a tendency toward vertical development on the upper surface of a sea of clouds covering the Alps. Illustration 4b, photographed from about 3,000 m (about 10,000 ft), shows a cumulonimbus cloud with anvil, or thunderhead, the characteristic upper portion. Low, ragged clouds frequently are under the base. The true profile of this cloud could not be seen from the ground except at such a great horizontal distance that atmospheric haze would obscure the view.

Cirrus clouds at sunset take on a deep reddish hue and hold this color long after the sun has disappeared below the horizon.

Banner clouds appear near the tops of mountains and have streaming, constantly changing shapes. These clouds are caused by strong, cool winds that blow over the mountain, causing condensation of moisture in the warmer air on the lee side.

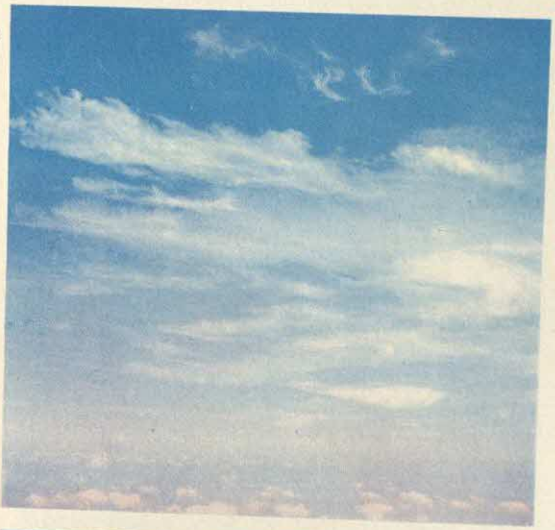
Compound cumulus clouds are huge, rolling clouds that are most often seen on summer afternoons. They are of interest because of their vast size, and because of the rapid changes they undergo as they sweep across the sky. It is worthwhile to document the growth and change of this kind of cloud by photographing the same part of the sky, at intervals of five or ten minutes, with a camera mounted on a tripod.

AERIAL PHOTOGRAPHY

It is seldom possible to see the true contours of clouds from the Earth's surface. Most clouds are flat on the surface they present to the Earth; their more interesting rounded or towering contours are on the upper surface. A better view of many types of clouds can be obtained from an airplane, or from high on a mountain. Photography under these conditions may require different exposures, however, as light at higher altitudes is more intense than near sea level.

5

a



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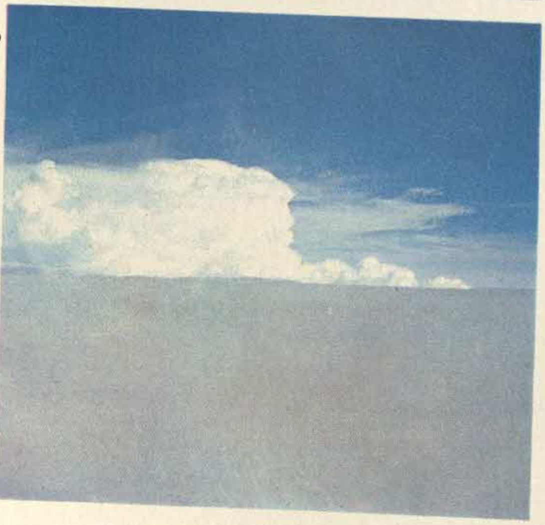
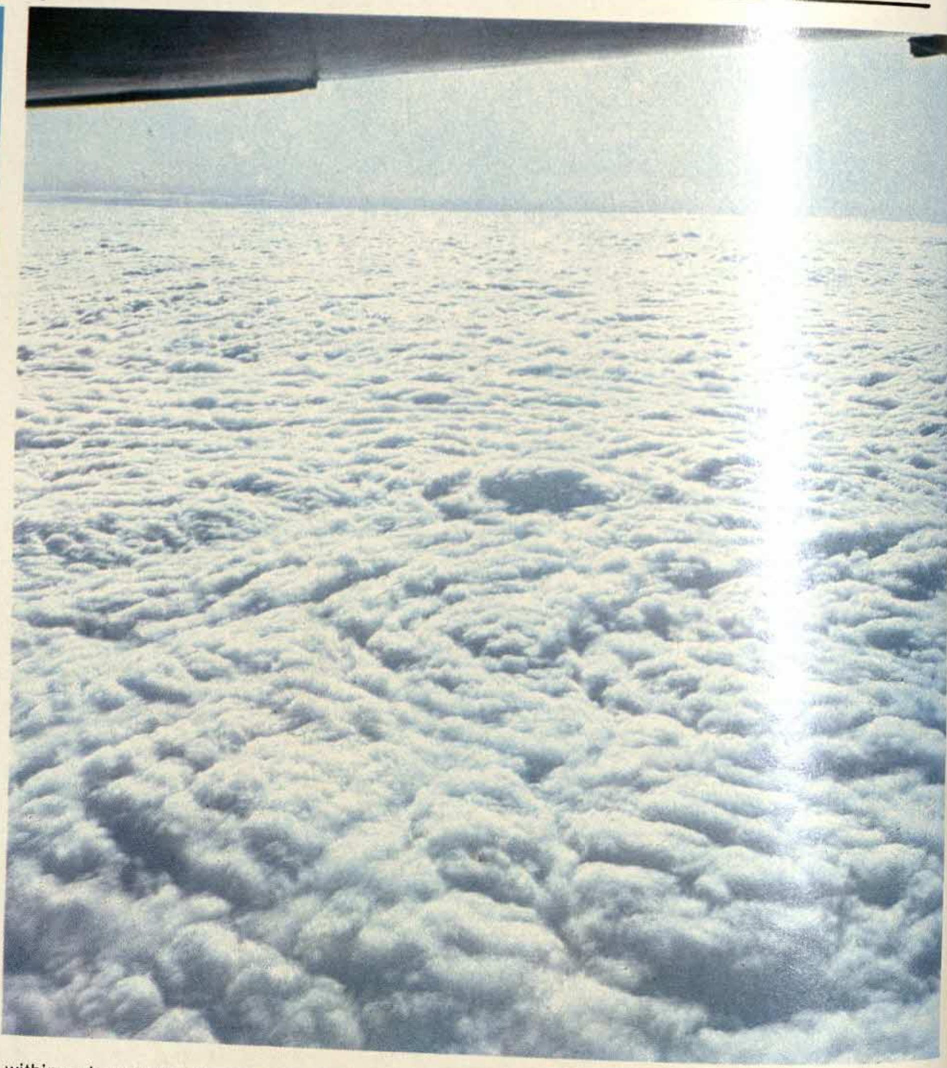


c



HOW CLOUDS CHANGE WITH THE WEATHER—A very interesting series of photographs can be taken to document the sequence of cloud types that accompany a change in the weather, such as the arrival of a warm or cold air mass. A typical sequence is shown in these three photographs.

After a number of calm, sunny days when the sky is clear, feathery cirrus clouds may appear high overhead (Illustration 5a). These forecast the arrival of less pleasant weather within a day or two. The next clouds to appear are rounded cumulus clouds (Illustration 5b); they may increase in number until they cover most of the sky. Finally, low-hanging horizontal layers of stratus clouds (Illustration 5c) obscure the sky, and rain falls. A drop in temperature usually accompanies this sequence of clouds. After a day or two a clearing trend occurs. The clouds break up, and areas of blue sky appear between them. Soon the sky is clear again; the weather is calm and sunny until a new air mass approaches.

Photographic documentation of a change in the weather may complement observations made with meteorological instruments, and contribute to an understanding of atmospheric phenomena. At the same time, the project may produce photographs of rare beauty. The delicate clouds that forecast the change and the billowing giants that bring electrical storms and high winds are among the most spectacular sights nature offers.

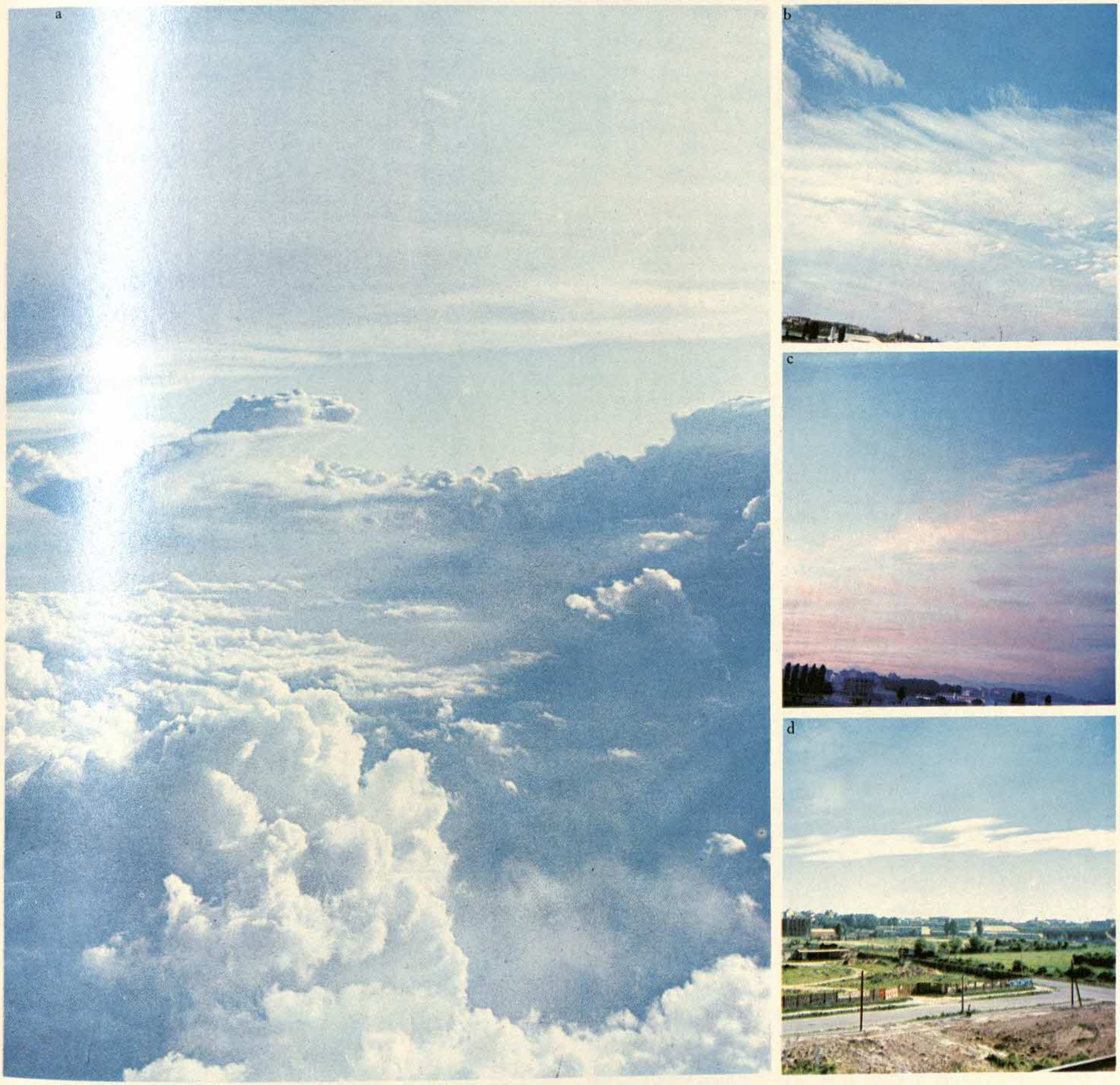
6

PROPER TIMING—The person who wishes to photograph different types of clouds must be ready to take pictures as soon as the clouds appear. Clouds change rapidly, and the right time for photographing a certain cloud formation may be of very short duration. A long time may pass before the same kind of cloud formation appears again.

In particular, alertness and a ready camera are required in aerial cloud photography. Because the airplane travels at high speed, the best point of view from which to photograph a certain cloud may be passed within seconds.

The illustrations shown here are cloud photographs that were taken just as soon as the opportunity was presented. Illustration 6a, taken from an airplane, shows three different types of clouds. On the lower level are small cumulus clouds; above them are larger cumulus clouds with advanced vertical development. Still higher, altostratus clouds spread across the sky.

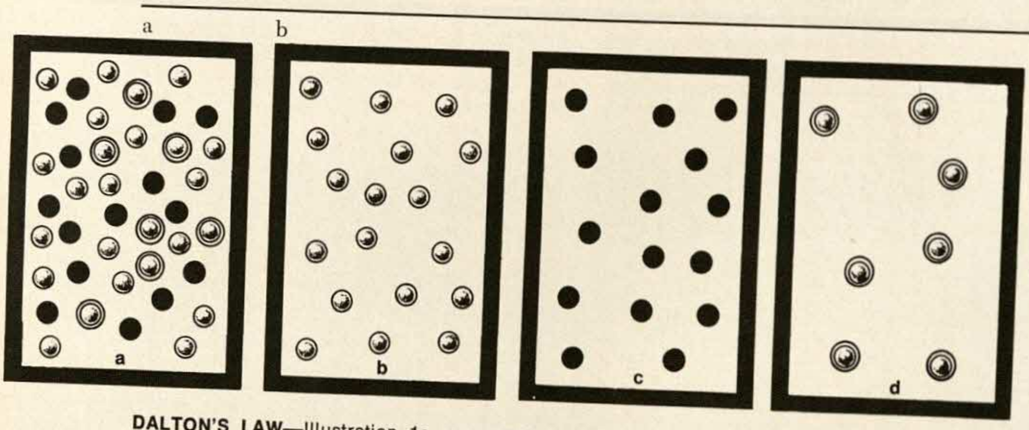
In Illustration 6b the clouds that appear at the border between clear and cloudy parts of the sky are cirrus clouds with tufts. Illustration 6c shows cirrus clouds at sunset. Because these clouds are very high, they are visible from a great distance, and they show the red rays of the sun for a long time after the sun disappears. Illustration 6d shows very high clouds of an unusual shape called whaleback.



ABSOLUTE AND RELATIVE HUMIDITY

the water in the atmosphere

1



DALTON'S LAW—Illustration 1a represents a container holding 40 molecules of three different kinds, all in a gaseous state. The three kinds of molecules in the container **a** are represented by spheres of different design; the shape and size of the molecules are of no importance in this instance, nor is their chemical nature. It is assumed that the temperature and density of the gases inside the container are such as to create a pressure of one atmosphere.

If the three kinds of molecules are separated into containers **b, c,** and **d, b** contains 18 molecules, **c** 15, and **d** 7. The pressure in these three containers will be 18/40 = 0.45 atmospheres; 15/40 = 0.375 atmospheres; and 7/40 = 0.175 atmospheres. This is called Dalton's law of partial pressures or Dalton's law, which states that the pressure exerted by a mixture of gases is equal to the sum of the separate pressures that each gas would exert if it alone occupied the entire volume. The law is applicable to water vapor.

Wate; vapor may be one of the components of atmospheric air, but when the temperature drops below 100° C (212° F) or when the pressure drops below one atmosphere (not a common occurrence), the water may condense.

2

THE VAPOR PRESSURE OF WATER—In this experiment, a quantity of water is placed in a cylinder closed at the top with a hermetically fitted piston so that the pressure on the surface of the water is determined solely by the pressure exerted by the piston **a** (Illustration 2a). If the piston is lifted to a certain height above the water, creating a vacuum between the surface of the water and the piston **b** (Illustration 2a), the system would no longer be in equilibrium, and part of the water would rapidly evaporate, filling the void with vapor.

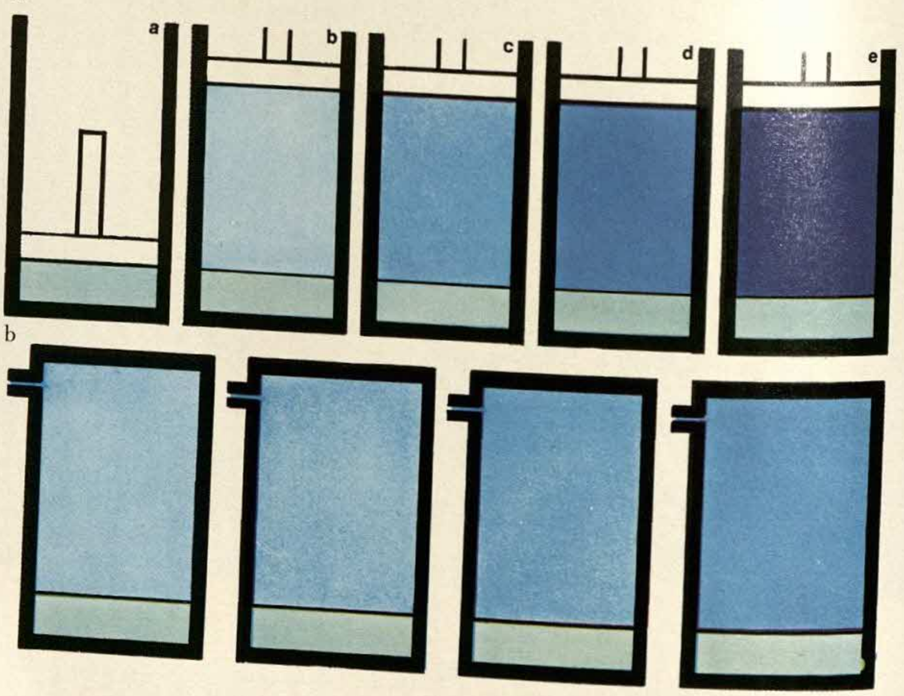
There is no correlation between the atmospheric pressure and the vapor pressure; the former depends on the force of gravity and on the mass of air above the surface of the Earth, while the vapor pressure depends only on the temperature. If the temperature at **b** were 20°, and it rose successively to 40° **c,** 60° **d,** and 80° **e,** the vapor pressure would rise with the temperature and the vapor within the cylinder would become increasingly dense.

However, if the cylinder were open to the atmosphere through a capillary tube, as in Illustration 2b, and water were poured into the cylinder, the water would evaporate over a period of time and fill the space above with vapor. The air above would be partially driven out by the pressure of this vapor, according to Dalton's law. The four containers shown represent the system at the same temperatures as containers **b, c, d,** and **e.** The partial vapor pressure in these containers is the same as the water vapor pressure in closed containers at the same temperature.

If one of the containers is heated, the partial pressure of the water vapor increases. If the container is cooled, the partial pressure decreases, and the humidity of the air decreases as well.

In those containers in which the air contains the maximum humidity consistent with the temperature at which the experiment is conducted, the air is said to be saturated with water vapor. The table (Illustration 2c) shows the values for partial pressure of water vapor at various temperatures. At 100° C, the boiling point of water, the vapor pressure rises to 760 mm of mercury; but it does not drop to 0 at 0° of temperature, because even ice has a vapor pressure. Molecules of water in ice have a tendency to pass directly into the vapor state by sublimation.

°C	mm Hg	°C	mm Hg
−15	1.436	45	71.88
−10	2.149	50	92.51
−5	3.163	55	118.04
0	4.579	60	149.38
5	6.543	65	187.54
10	9.209	70	233.7
15	12.788	75	289.1
20	17.535	80	355.1
25	23.756	85	433.6
30	31.824	90	525.76
35	42.175	95	633.90
40	55.324	100	760.0



It is difficult to believe that the sweltering air above a torrid desert under a burning sun contains more water vapor than the foggy atmosphere of a plain during a rainy winter. Yet this is so, and it is only one of several strange facts connected with the phenomena of relative and absolute humidity.

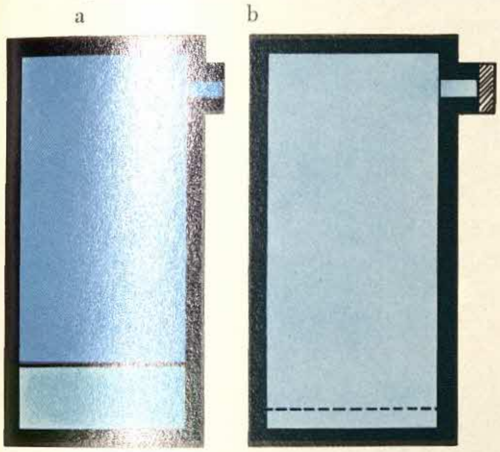
The Earth's atmosphere contains certain components in fixed proportions that never vary; these are oxygen, nitrogen, argon, and some other noble gases. So-called variable components are impurities contained in the lower part of the atmosphere and in water vapor. Many atmospheric phenomena depend on the percentage of water vapor contained in the air.

Because the water is in a vapor state, its study is complicated by the fact that a compressed vapor condenses. Other gases condense only when they are cooled below a certain critical temperature that is well below the ranges encountered in the atmosphere.

The starting point in the study and interpretation of water vapor in the atmosphere is Dalton's law of partial pressures in mixed gases—that is, the atmosphere.

3

a b



ABSOLUTE AND RELATIVE HUMIDITY—Once again, the container shown in Illustration 2b is filled with water to a certain level (Illustration 3a). After a while the system will reach an equilibrium; part of the water will evaporate, driving out the excess air. Once this state is reached, no further evaporation will take place unless some of the water vapor escapes through the tube or condenses. In this condition of equilibrium, the atmosphere is saturated with water vapor, which occupies part of the volume of the container and has a particular density relative to the air.

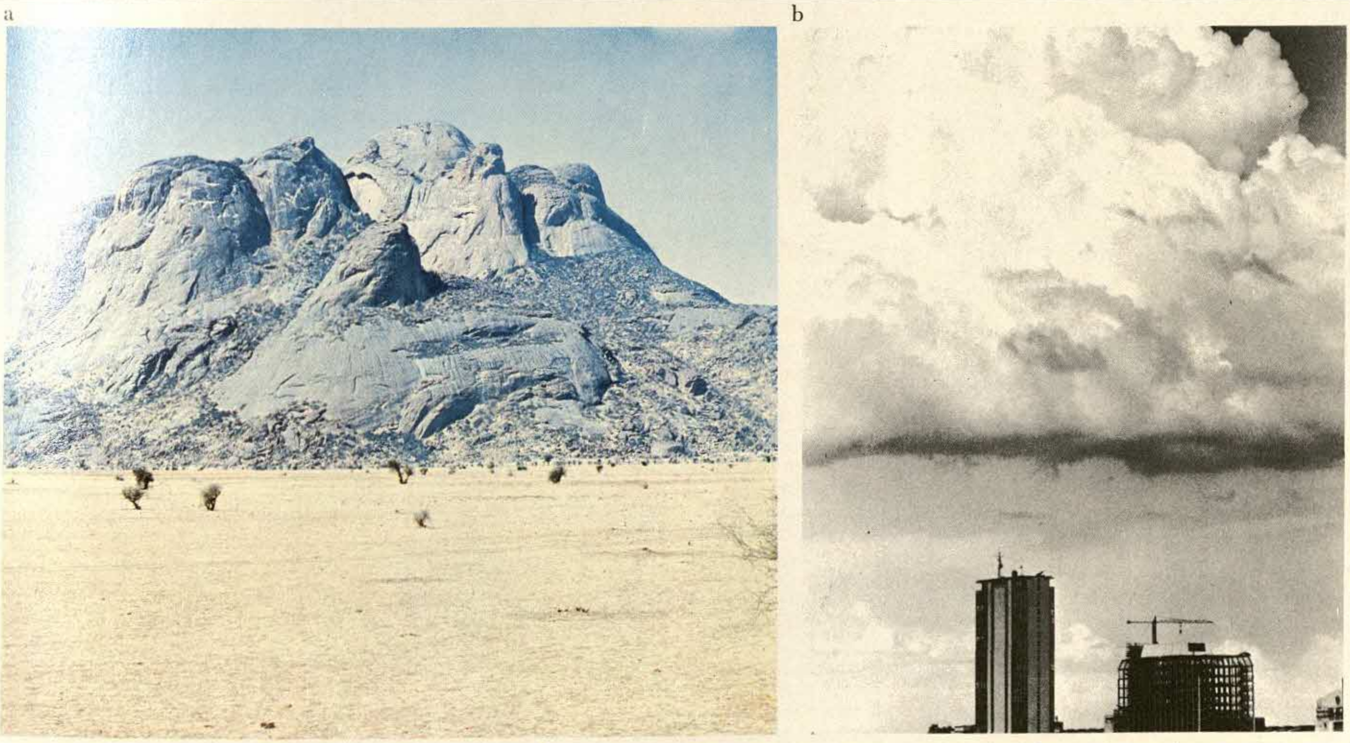
As the table (Illustration 2c) shows, if the system is at 20° C, the partial pressure of the water vapor is 17.535 mm of mercury. From this, the absolute humidity of the air can be computed; this is generally expressed in grams of water per cubic centimeter of air, or more simply by the partial vapor pressure of the water, which is known from the vapor pressure at any given temperature. This absolute humidity is of a saturated system at a known temperature in which water, water vapor, and air are all present in equilibrium.

In Illustration 3b the experiment is repeated using only a small amount of water, which is allowed to evaporate entirely. If more water is added and the opening to the external atmosphere is sealed, some of the new water will evaporate, indicating that the air within the container is no longer saturated with water vapor. The partial pressure of water vapor within the container is less than the partial pressure of saturated vapor at that temperature. The ratio between the vapor pressure and the saturated vapor pressure at the same temperature is called the relative humidity.

A cubic meter of air containing a given quantity of water vapor has the same absolute humidity no matter what the temperature is, but its relative humidity varies with the temperature. Relative humidity is a most important factor, for it determines the point at which the water vapor will condense.

4

a b



TWO DIFFERENT SITUATIONS—In the desert (Illustration 4a) the relative humidity usually reaches about 15 percent. When the temperature is 45° C or 113° F (in the desert, much higher temperatures may prevail), the partial pressure of water vapor is 10 mm Hg; thus the desert has a very high absolute humidity.

In Illustration 4b a cloud has developed with a very flat bottom surface. This indicates that hot air from the ground has risen high enough to cool to its dew point, the temperature at which it condenses. At this temperature the relative humidity is so high that the water vapor condenses in small droplets, causing fog. The relative humidity, therefore, has reached 100 percent, but this condition will be reached at 0° C when the absolute humidity is only 4.6 mm Hg of partial pressure—less than half the water vapor present in the hot air over the desert. Therefore, in the fog or in a cloud where the air is saturated with water vapor, less water vapor may be present than in the desert air.

The fact that the relative humidity affects the propensity of water to condense or to evaporate is felt by a perspiring person whenever the environmental temperature rises. If the relative humidity is high, perspiration evaporates slowly and, no matter how copious, has no cooling effect because only the smallest amount evaporates. Much less perspiration in dry air will evaporate very rapidly, taking away the heat. For this reason, the high temperatures of hot climates are more bearable when the air is very dry.

5

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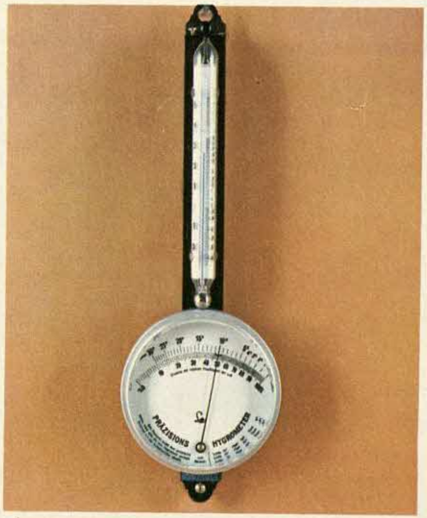

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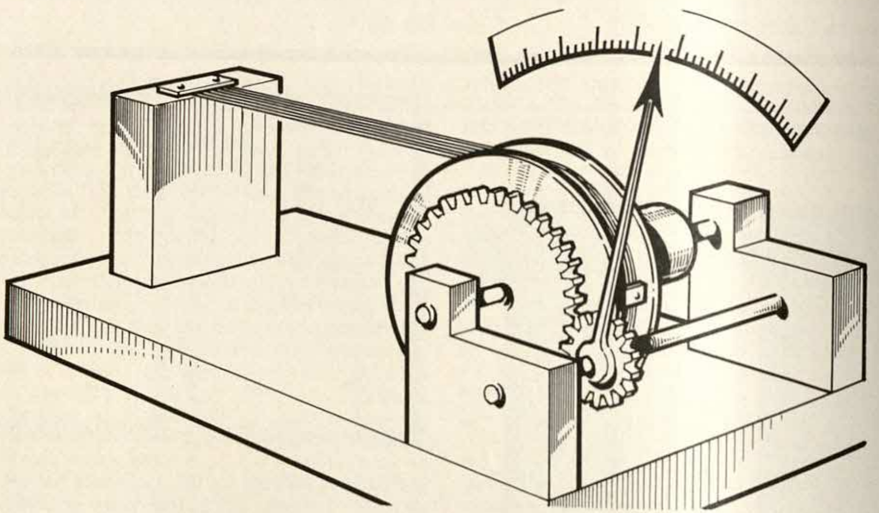

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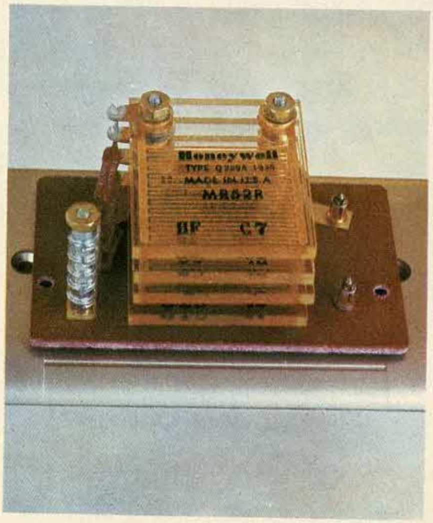

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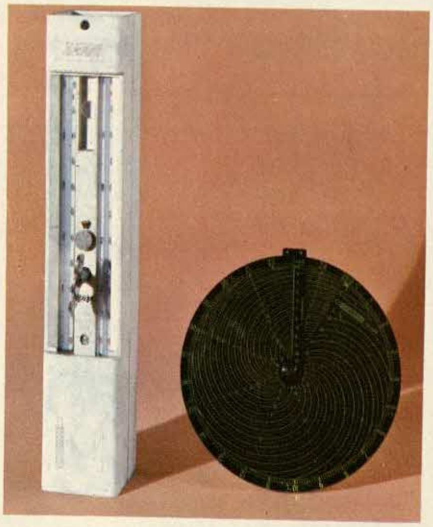

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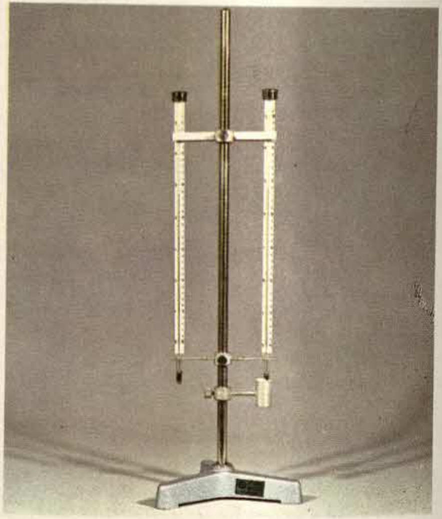


METHODS OF MEASURING RELATIVE HUMIDITY—The absorption of water by hygroscopic materials alters their properties, making possible their use for measurement of the relative humidity of the air. At a higher relative humidity, the materials absorb more water. The two instruments shown in Illustration 5a and 5b measure relative humidity on the basis of the hygroscopic properties of materials used in their construction.

The hair hygrometer (Illustration 5a and 5a′) contains a specimen of blond hair (blond hair is more hygroscopic than any other color) stretched between a fixed point and a movable point held by a spring. The movable point shifts according to the humidity, moving an indicator hand by a system of gears.

Another type of hygrometer (Illustration 5b) is based on the conductivity of lithium salts spread over a plate of insulating material; the salts constitute a resistor that varies according to the water content of the salts, which in turn varies with the humidity of the air. Balloon-mounted hygrometers used for high-altitude soundings work on this principle.

The psychrometer (Illustration 5c)—a thermometer set in a bath of evaporating ether—measures relative humidity according to the principle that the temperature of condensation of the air's humidity, the dew point, depends on the relative humidity. The ether cools the exterior of its container, and the surface shows the atmospheric water condensing in the form of dew. The thermometer gives a figure that can be translated into relative humidity according to the table shown to the right of the hygrometer.

Still another way to measure relative humidity is by measuring the speed of evaporation of water. Two identical thermometers are used, one with its bulb exposed and the other with its bulb covered with wet gauze (Illustration 5d). The latter always shows a lower temperature because it is cooled by the water evaporating from the gauze. The lower the humidity of the air, the greater the cooling effect of the gauze. A table shows the relative humidity based on the correlation of the actual temperature, as shown on the dry thermometer, and the difference in temperature as shown on the two thermometers.

Although the methods shown in Illustrations 5c and 5d may seem more laborious than the others, they are the ones most frequently used. The hair hygrometer is less accurate, and at low levels of humidity it scarcely moves at all. The lithium-salt hygrometer registers the humidity very slowly, and requires costly instrumentation to obtain a precise reading.

THE WIND | its study and measurement

Wind—the movement of air across the surface of the Earth—is a basic indicator of changes in weather. Thus, the analysis of the winds is one of the most important meteorological studies. Simply by observing wind direction, a meteorologist may be able to forecast weather changes—knowledge that is of vital interest to the farmer, the navigator and the traveler, the businessman, and, in the case of violent storms, the community at large. Knowledge of the winds in a given area is important, too, so that buildings may be constructed in such a way that they can withstand the strongest force likely to be encountered.

Fortunately for mankind, it is relatively easy to observe, interpret, and collate the various meteorological phenomena taking place: wind, rain, atmospheric pressure, humidity, and the like. Complicated apparatus is not necessary; only simple instruments are required, some of which can even be made at home. For example, a weather vane and an anemometer can be made by an amateur, and a thermometer and a hygrometer are obtainable at low cost.

WHERE MEASUREMENTS ARE TAKEN

The best place to measure the wind is an elevated area—a roof or raised terrace, for example. It is important that the area be away from tall buildings or high trees; wind blowing against such obstructions might be slowed down or diverted from the measuring place. The ideal solution would be a tower made of thin wood or metal slats and standing about 5 to 10 m (about 16 to 33 ft) high in the middle of an open field. This ideal

1

a

b

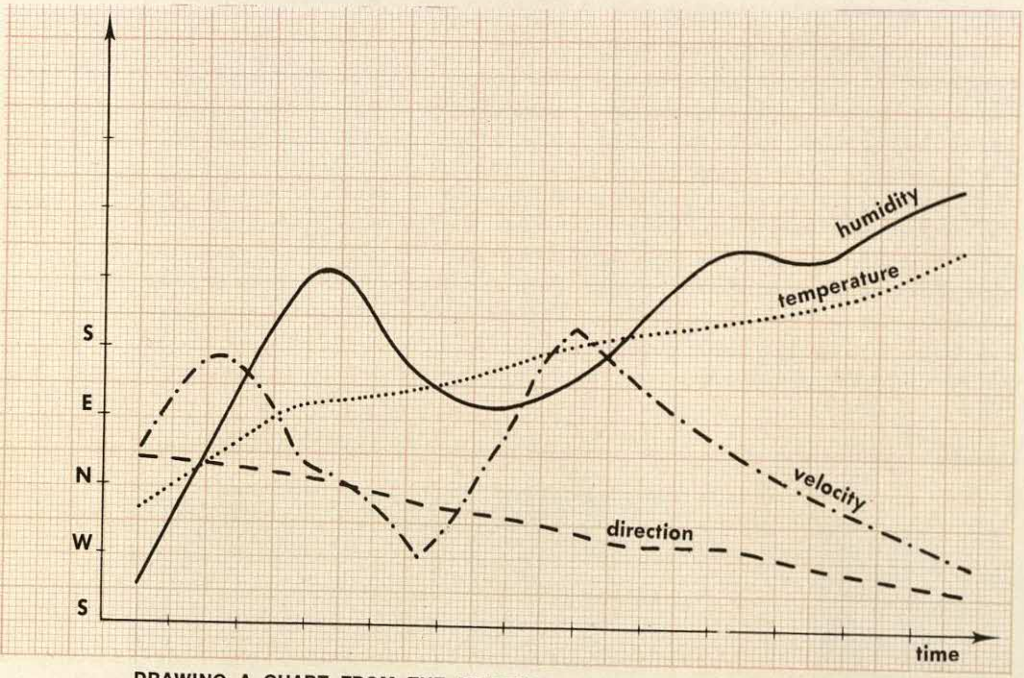
FOUR INSTRUMENTS FOR COLLECTING IMPORTANT DATA—To describe the most important elements of the wind, four types of measurements are needed: wind direction; wind velocity; air temperature; and air humidity. The instruments needed to obtain these measurements are, respectively: a weather vane—a simple plate of wood or metal that rotates around a vertically fixed axis according to the direction of the wind; an anemometer; a thermometer; and a hygrometer.

The thermometer and the hygrometer (Illustration 1a) are inexpensive instruments. The anemometer (Illustration 1b) is somewhat more expensive, but not prohibitively so; one can be built at home. A weather vane is easily made.

Some winds blow constantly for days on end; during this time, their velocity, temperature, and humidity vary only slightly. Other winds continually vary; for example, a storm passing overhead may cause a rapid change in the wind direction. Therefore, significant readings must be taken with greater or lesser frequency according to the conditions being studied.

Measurements read from the instruments are recorded in a log, along with the time that the measurements are taken. This is necessary so that a progress chart of the observations may be drawn.

2



DRAWING A CHART FROM THE MEASUREMENTS—When observations have been completed (for example, the course of the wind during a storm), measurements are recorded on a chart. A rectangular sheet of graph paper with the longer side on the horizontal is preferred, as shown in the illustration. A straight line at the bottom represents the time, with, for example, one square for each interval between readings. A point is recorded on the chart for each of the four readings made at each time interval; thus, a succession of points appears, representing wind direction, temperature, humidity, and wind velocity. By joining these points, an overall view of wind activity during the period of observation is quickly obtained.

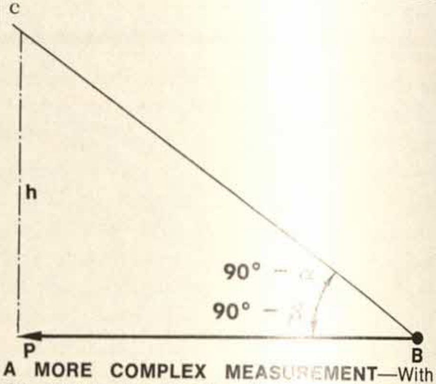
is difficult to achieve, and other elevated areas must usually suffice.

READING AND INTERPRETING WIND DIAGRAMS

For the best analysis, data collected at a wind observation station should be charted. In a coastal city, for example, if the line representing wind direction points south at the same time that the line representing humidity is rising, the indication is that the wind coming from the south has become humid because it has begun to blow from the sea. In another case, measurements taken in a mountain valley where there are no predominantly strong winds will reflect the fact that the evening breezes from the mountain are cool, while those during the day are warmer.

Meteorological phenomena may be interpreted in terms of a limited area as well as of a larger region. For example, a strong wind may blow from the same direction for several days, causing only a small thermal variation (the difference between minimum and maximum temperatures of a day). When the wind finally subsides, the temperature is about the same as that of the region in which the wind originated. Analysis leads to the conclusion that, in the Northern Hemisphere, the temperature will rise when a south wind blows and will fall when a north wind blows. Temperature data of nearby regions are usually found in local newspapers.

3



A MORE COMPLEX MEASUREMENT—With the simple instruments that have been described, the velocity of wind near ground level can be accurately measured. Often, however, it is desirable to determine wind velocity at different altitudes. For example, it is very interesting to compare wind velocity at ground level with that a few meters above the ground.

The movement of air is hampered by friction against the ground as well as by such obstacles as buildings, hills, trees, and waves. As the altitude increases from a few meters to more than a kilometer, wind velocity may be greater—but it may also be less, or zero. Sometimes, the wind may be blowing in one direction at ground level and another direction higher up.

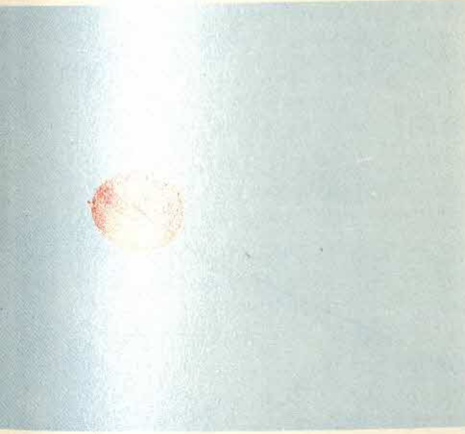
It is more difficult to measure these variations of velocity according to altitude, but an instrument that makes it possible is simply constructed. A brightly colored pilot balloon ½ to 1 m (about 1½ to 3 ft) in diameter, filled with hydrogen or natural gas, will rise to a height of several thousand meters, and can be seen through binoculars at a great distance. Night observations may be made by attaching a pen-size flashlight.

The balloon's movement can be followed with two optical transits placed about 1 km (about ½ mi) apart. Its altitude is measured with respect to the horizon and its position with respect to the north. Illustrations 3a and 3b show how the two instruments are placed; Illustration 3c shows how the readings, taken simultaneously by two observers, are recorded.

From the course of the balloon (Illustrations 3d, 3e, and 3f), and from the times at which it is clocked at various points, it is possible to calculate its speed—and, therefore, the velocity of the wind. This technique may be refined, even by an amateur, to extend the readings to the stratosphere to a height of almost 20 km (about 12 mi).

f

e



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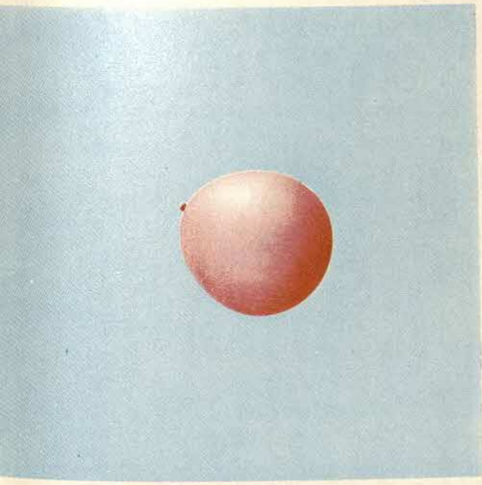

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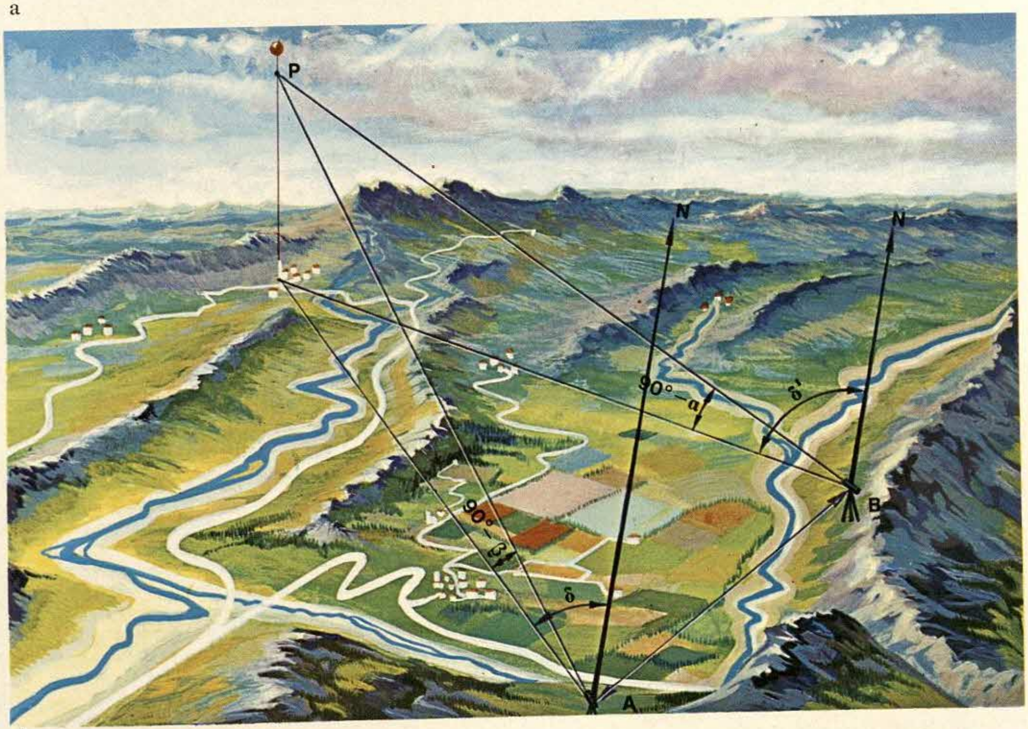

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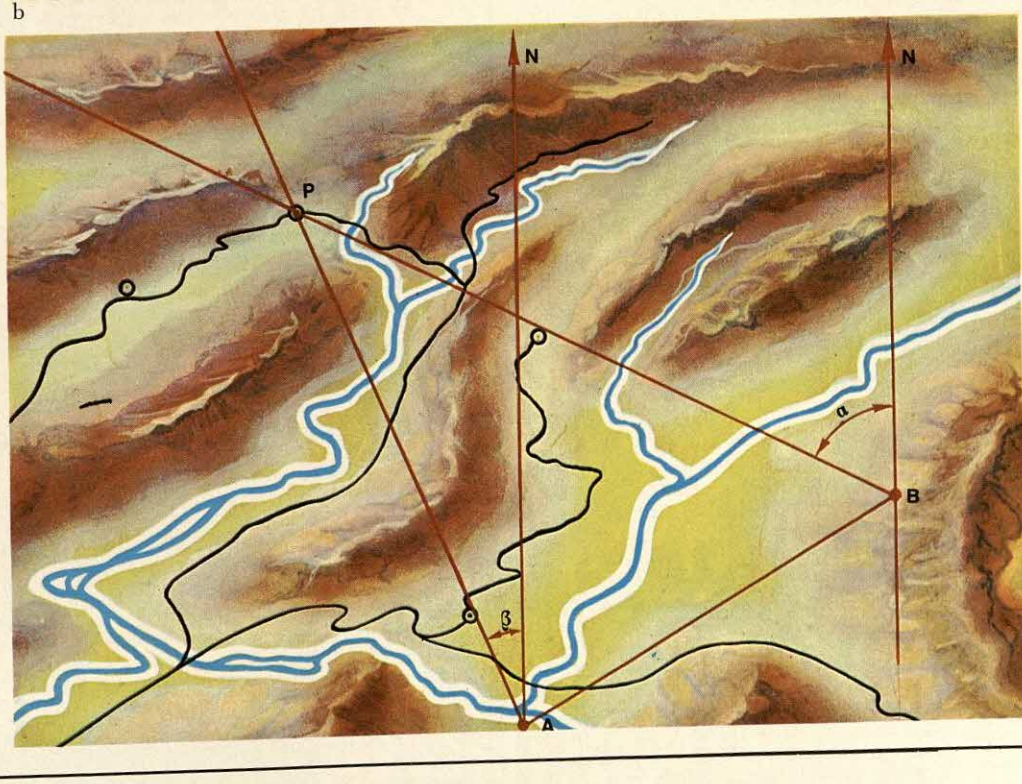

FACTORS THAT INFLUENCE CLIMATE

temperature and rain: mathematics and caprice

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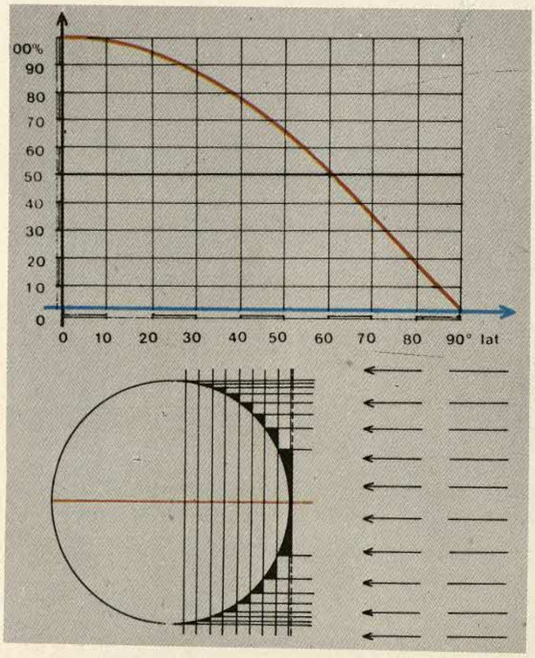
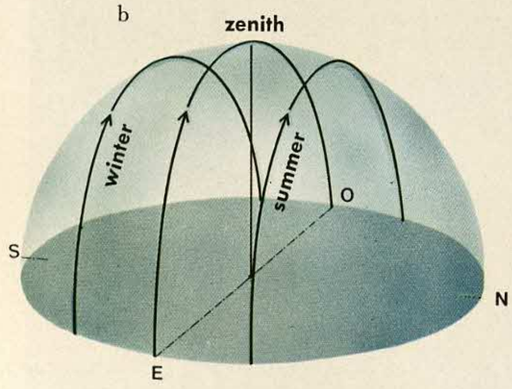


THE PRIME FACTOR: SOLAR RADIATION— The Earth receives maximum heat and light from the sun only when the atmosphere is clear. If mist or fog are present, or if clouds cover the sky, much of the sun's radiation is reflected back into space and contributes little to the warming of the Earth. Other factors determine how much of the sun's heat is retained or lost by the Earth. Ground covered by snow or ice reflects heat back into space rather than retaining it. When the sky is clear by day but cloud-covered by night, heat tends to accumulate because the night clouds impede radiation from the black body of the warm earth into space. Conversely, when the sky is cloud-covered by day but clear at night, a great loss of heat occurs. These factors are not constant, however, and they influence climate for only part of the year.

Conditions of prevailingly cloudy or clear skies are generally constant for long parts of the year. The former is characteristic of the northern latitudes, and the latter is characteristic of desert regions.

Scientists estimate that nearly one-half of the sun's energy received by the Earth is lost by reflection from the atmosphere or from the Earth's surface, and that only about one-half is absorbed and transformed into other forms of energy.

b



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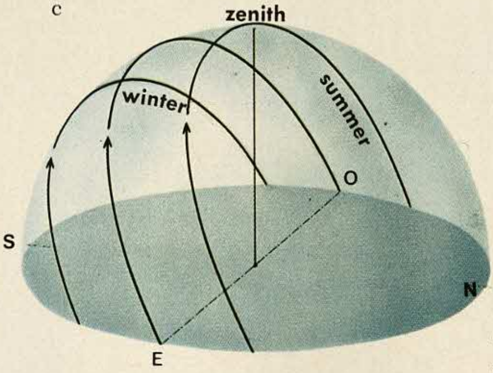


The solar radiation that reaches the Earth's surface is effective according to the angle at which the sun's rays strike the ground, and the length of the day. In Illustration 1a, 100 percent represents the quantity of heat the Earth's surface receives from the sun when the sun is at the zenith, a condition that occurs only in the tropic zone. The graph shows the lessening effectiveness of the rays as they are inclined. When the inclination is 80° with respect to the horizon (10° from the vertical), the rays have an effectiveness only 98.5 percent that of vertical rays. This is because slanted rays are scattered over more of the Earth's surface, and because they have to pass through more of the Earth's atmosphere before reaching the surface.

At noon on a summer day in the temperate zone, the sun appears very near the zenith, and the sun's rays have almost the same effectiveness as in the tropic zone. The summer day in the temperate zone is actually longer than the tropic day. As a result, summer days in the temperate zone may be as warm as in the tropics.

Illustration 1b shows the path of the sun at different times of the year as seen from a point on the equator. The sun's path is perpendicular to the horizon, and days and nights are of equal length. Illustration 1c shows the path of the sun as seen from a point on the Tropic of Cancer, the northern boundary of the tropic zone. The sun's path is inclined toward the south, and summer days are a little longer than winter days, but the seasonal variation in heat received from the sun is not great although other climatic factors may make it seem great.

The usual task of a meteorologist is examination of the climate of one locality. He uses numerous scientific instruments to make observations and collect data concerning the weather. He may also study the vegetation, wildlife, and geological features of the landscape, because all show the influence of climate.

On the basis of these studies, the meteorologist can describe the climate of his area, but he cannot explain it. To learn why the climate is as he finds it, he must look beyond the boundaries of his locality to the outside factors that influence weather. He will need to study maps and charts that incorporate thermal and meteorological data from all parts of the world.

Climate is a complex phenomenon in which the quantity of heat the Earth receives from the sun plays a determining role. This prime factor is, however, influenced by others, such as the movement of air masses and the amount of moisture in the air. Geography is also a major factor: nearness to the ocean or position in relation to a mountain chain influences the climate of an area, as does the distribution of land and sea areas. In combination, these factors determine the amount and kind of cloud cover over a locality; and this, in turn, determines how much of the sun's heat and light actually reaches the Earth's surface.

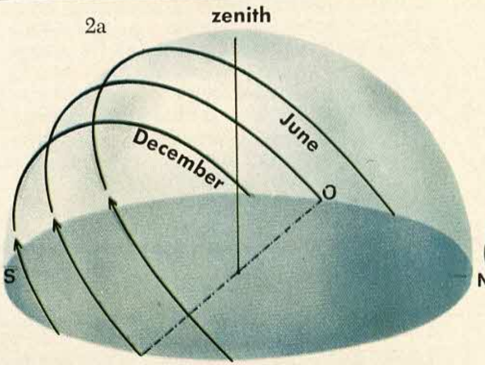
Some factors exert a constant influence. A mountain chain, for example, always acts in the same way on winds from the same direction. The modifying effect of the sea is also, in most cases, constant. Other factors, such as the winds themselves, vary greatly. Winds are largely caused by the thermal action of the sun, which, in most parts of the world, changes with the seasons. In a few parts of the world a nearly constant wind blows from the same direction all year long, but in most places the winds at ground level are capricious and variable.

Some of the principal factors that influence the world's climates are discussed in the following paragraphs. One important characteristic of climate that is not considered here is variability as a function of altitude, the condition that accounts for the presence of vegetation

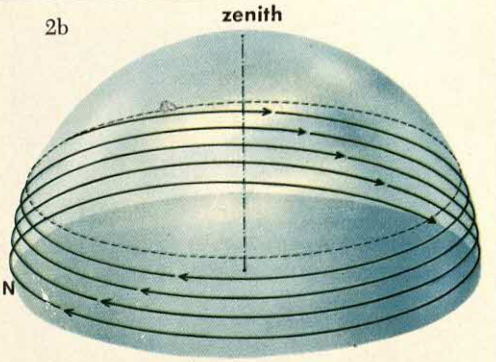
SOLAR RADIATION IN THE TEMPERATE AND POLAR ZONES—Farther from the equator, the seasonal variation in solar radiation received at the Earth's surface increases. Summer days are much longer than winter days; the sun approaches the zenith in summer but it hangs low near the horizon in winter. Illustration 2a shows the path of the sun at different times of the year as seen from a point about halfway between the North Pole and the equator (the latitude of Minneapolis–St. Paul in the United States, or Milan in Italy). In December the sun remains above the horizon for only about eight hours; in June there are nearly twice as many daylight hours, and the sun climbs much higher in the sky.

Illustration 2b shows the path of the sun in summer, as seen from the North Pole. During the six-month-long polar summer the sun is always visible above the horizon. During the early part of the summer the sun appears higher in the sky each day. As the summer nears its end, the sun drops lower in the sky, day by day, until it skims the horizon and finally disappears below it. Then the six-month-long polar winter begins. As seen from the pole, the sun's path is a rising and falling spiral rather than a series of circles. The sun is never very high in the sky, but because of the length of the polar day the air temperature at the North Pole rises above 0° C (32° F), and the previous winter's snow melts off the pack ice that covers the Arctic Ocean.

2a



2b



THERMAL GRADIENT OF LATITUDE—This illustration shows approximate average temperatures at different latitudes, at noon, when it is summer in the Northern Hemisphere and winter in the Southern Hemisphere. In the Northern Hemisphere, temperatures range from 40° C (104° F) at the equator to 0° C (32° F) at the pole. In the Southern Hemisphere the temperature drops to −30° C (−22° F) at the pole.

Actual temperatures at the different latitudes may, of course, be very different from those shown on the chart, because of the irregular distribution of land and water masses on the Earth's surface. Solar radiation is absorbed by land but mostly reflected by the surface of the water; the oceans warm more slowly but hold heat longer, and tend to modify the climate.

The North Pole is not the coldest point in the Northern Hemisphere because the Arctic Ocean under the floating icecap modifies the climate. Much colder temperatures are recorded in landlocked areas of Siberia that are some distance from the pole.

The South Pole corresponds more closely to the coldest point in its hemisphere because it is near the center of a continental landmass and at a high altitude. The coldest temperature ever recorded, in Vostok, Antarctica (August 1960), was −197° C (−322.6° F).

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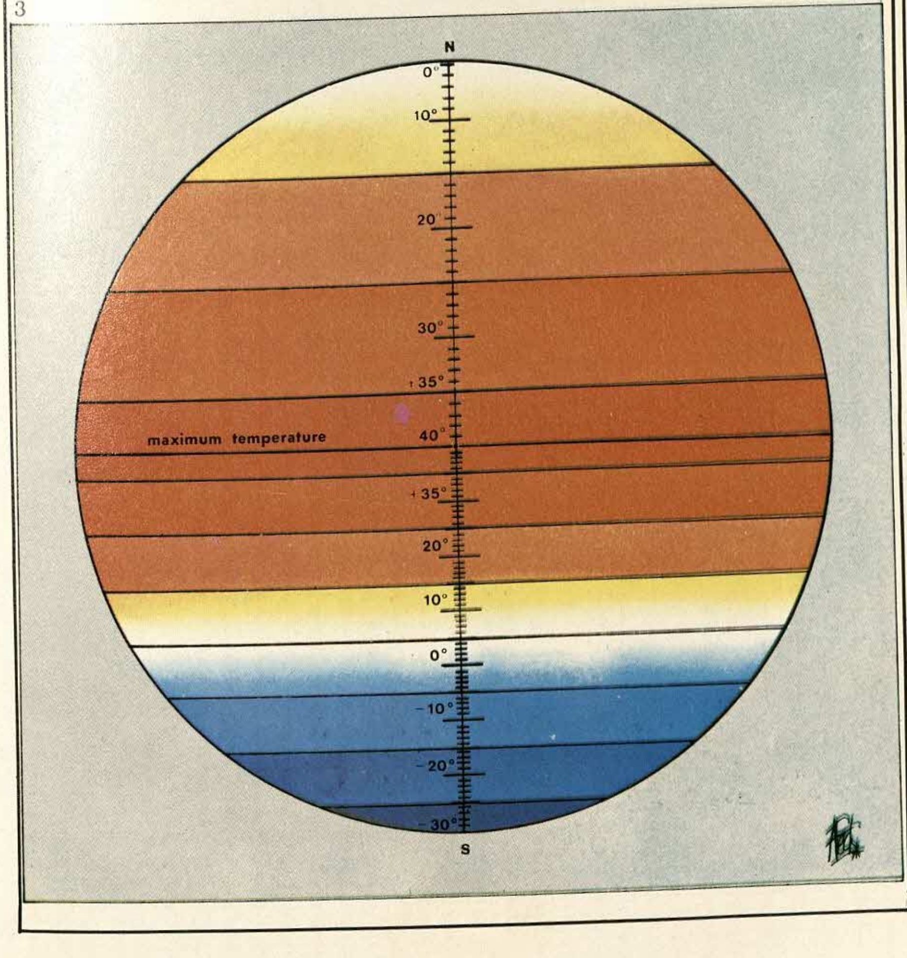

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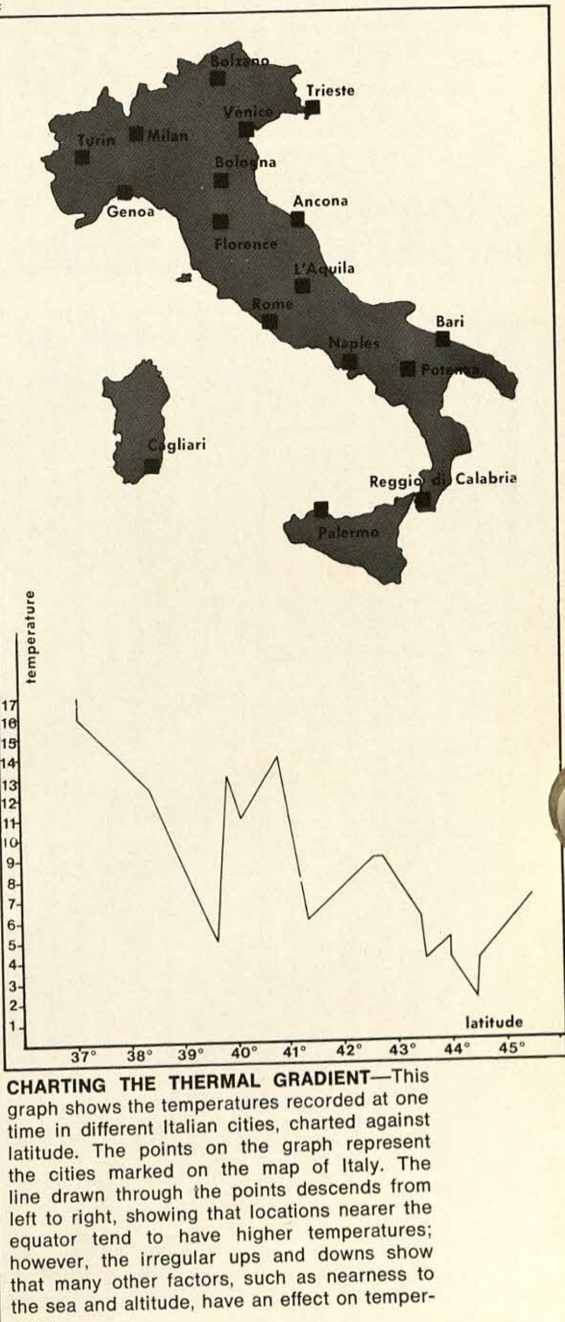


CHARTING THE THERMAL GRADIENT—This graph shows the temperatures recorded at one time in different Italian cities, charted against latitude. The points on the graph represent the cities marked on the map of Italy. The line drawn through the points descends from left to right, showing that locations nearer the equator tend to have higher temperatures; however, the irregular ups and downs show that many other factors, such as nearness to the sea and altitude, have an effect on temperature.

A similar chart can be made for any area by charting the high temperatures for different cities, as printed in newspapers or given on television, against the latitudes of the cities.

typical of the higher latitudes on the slopes of mountains near the equator.

Although much is known about the factors that influence weather, climatology is not an exact science. Many parts of the Earth are subject to variations in climate about which there is little agreement. In particular, the causes of long-term variations in climate are not thoroughly understood.

Climatic elements are observed at thousands of weather stations. Observations of the climatic elements should cover several decades in order to do an adequate job. From these observations, the frequency of various weather events and the range and frequency distribution of measured quantities can be obtained.

5

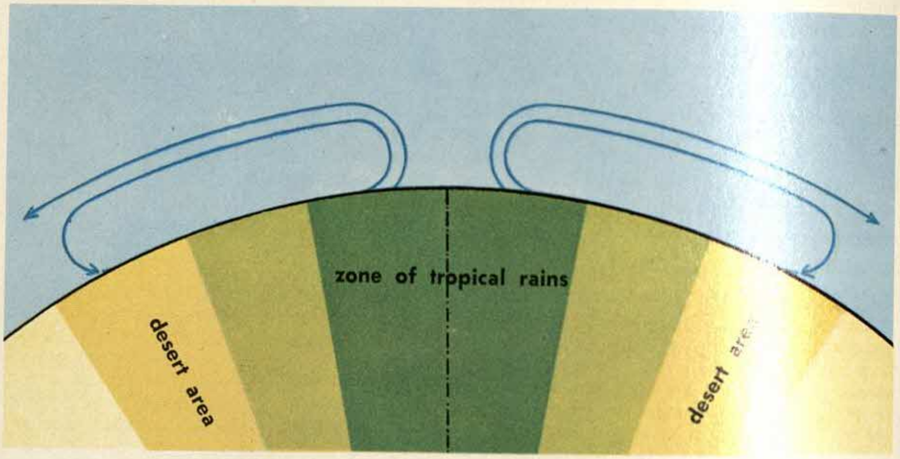
TROPIC RAINFALL AND DESERTS—Near the equator, where solar radiation is most effective, rains are heavy and frequent. Adjacent to the tropics, both north and south of the equator, lie desert areas where rainfall is scanty. This is due to the thermodynamic phenomenon shown in Illustration 5a.

Near the equator, warmed air is constantly expanding and rising. As the air rises, it cools. Moisture in the air condenses into droplets and falls as rain, and the air moves away from the equator. A part of this air descends to the Earth's surface along two belts that are roughly parallel to the equator, north and south of the tropic zone.

Because this air lost its moisture as it ascended, it brings no rain or cloud cover to the area where it descends.

Illustration 5b shows the belts where most of the world's deserts are located.

a



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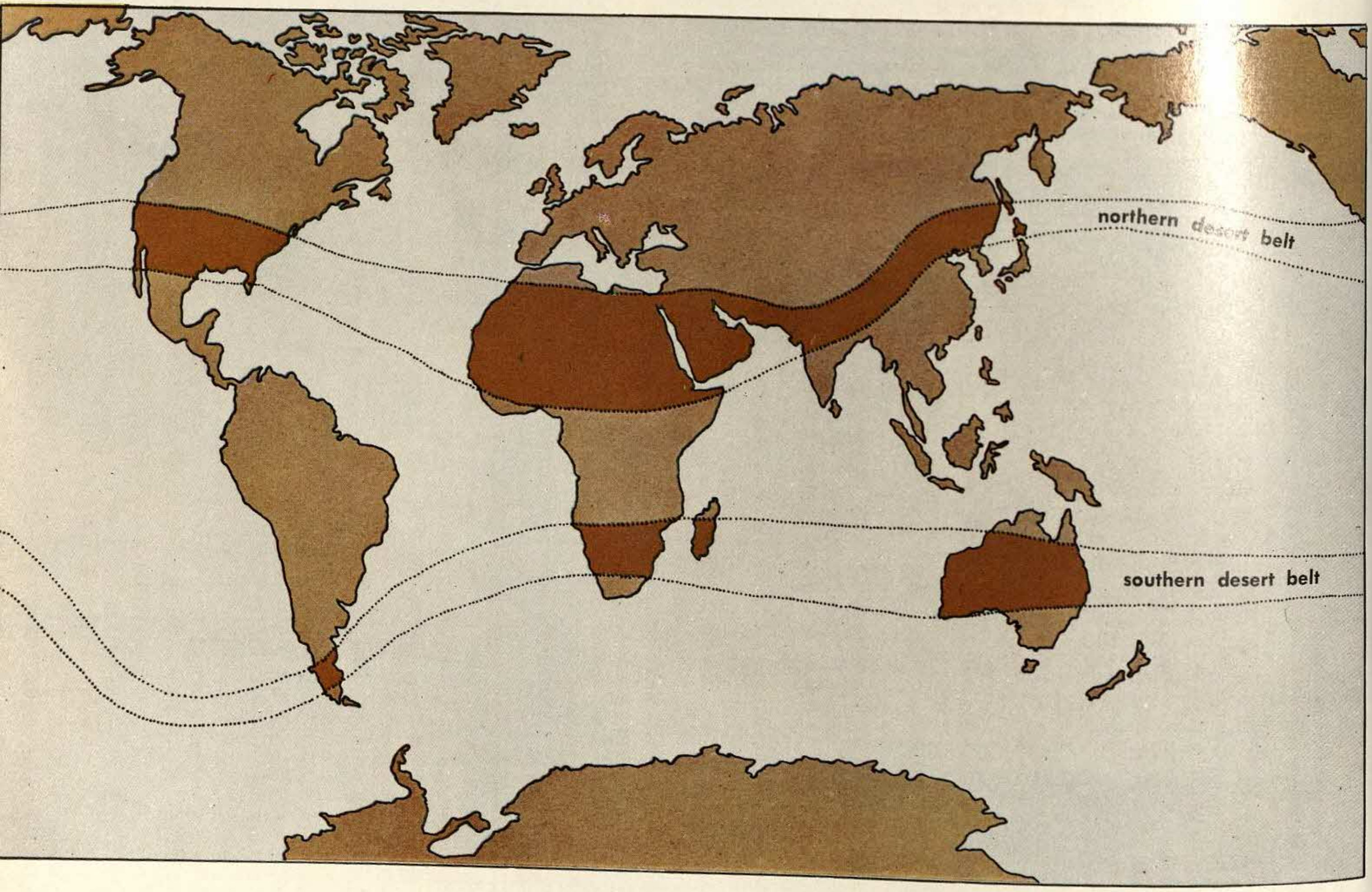
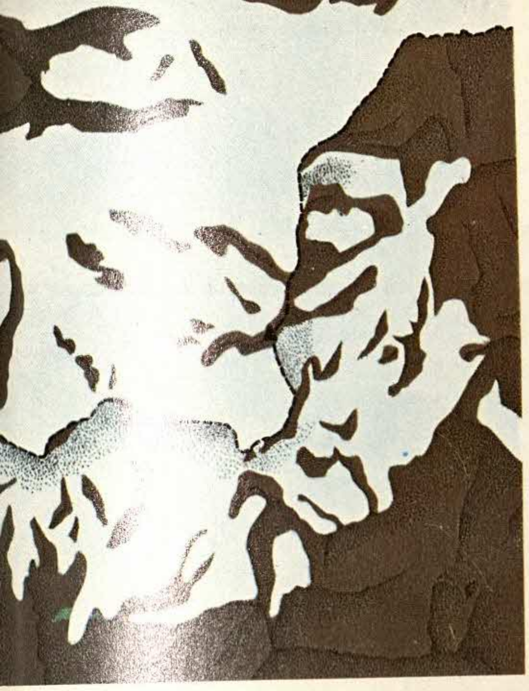




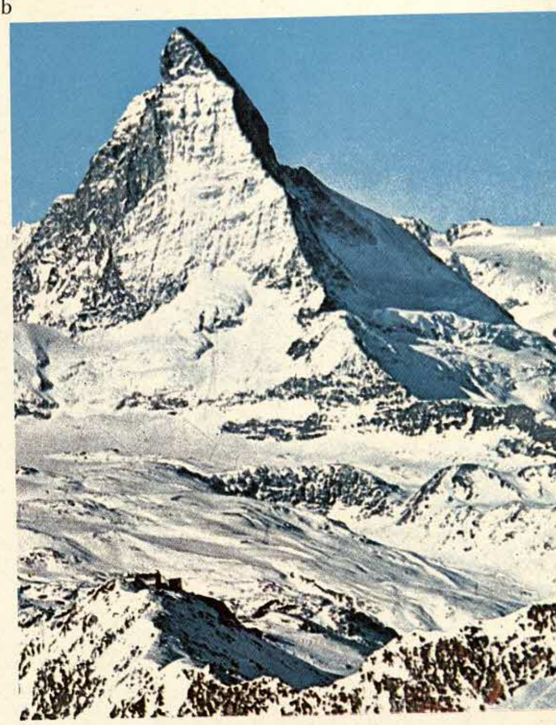
6a

HOW MOUNTAINS FORM CLIMATE BOUNDARIES—Abrupt changes in temperature are typical of the continental climate. The arrival of a new air mass can cause the temperature to rise or fall many degrees within a few hours. When mountains form wind barriers, the temperature on one side of the mountains may be quite different from the temperature on the other side, just a few miles away.

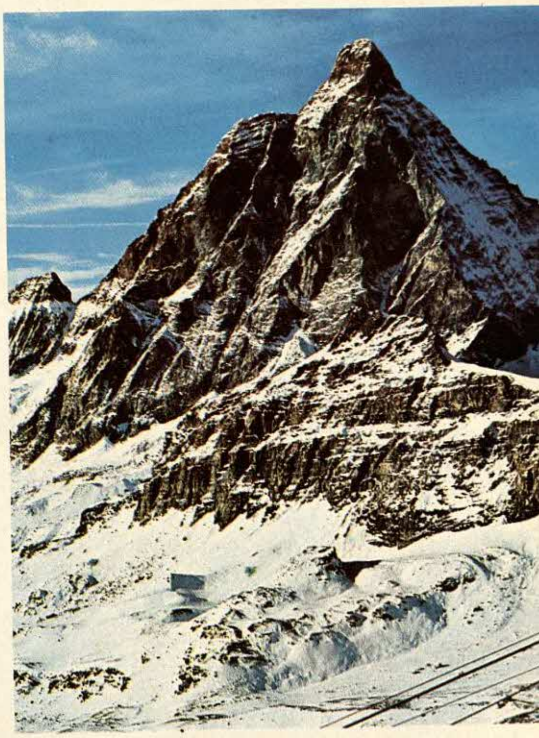
In some parts of the world the continental divide that separates two watersheds also separates climate zones. This occurs in the Himalayas, where the climate north of the highest peaks is much more severe than that south of the peaks. It also occurs, on a smaller scale, in the Alps. This map (Illustration 6a) shows the highest part of the Alps. The light-colored areas represent glaciers; the broken line is the continental divide between drainage systems. Obviously the glaciers north of the line are more extensive than those south of the line, indicating a difference in air temperature, although the angle at which the sun's rays strike the mountain slopes is also a factor.

Illustrations 6b and 6c show opposite faces of Mount Cervino in the Alps. The difference in snow cover indicates a considerable difference in temperature.

6b



6c



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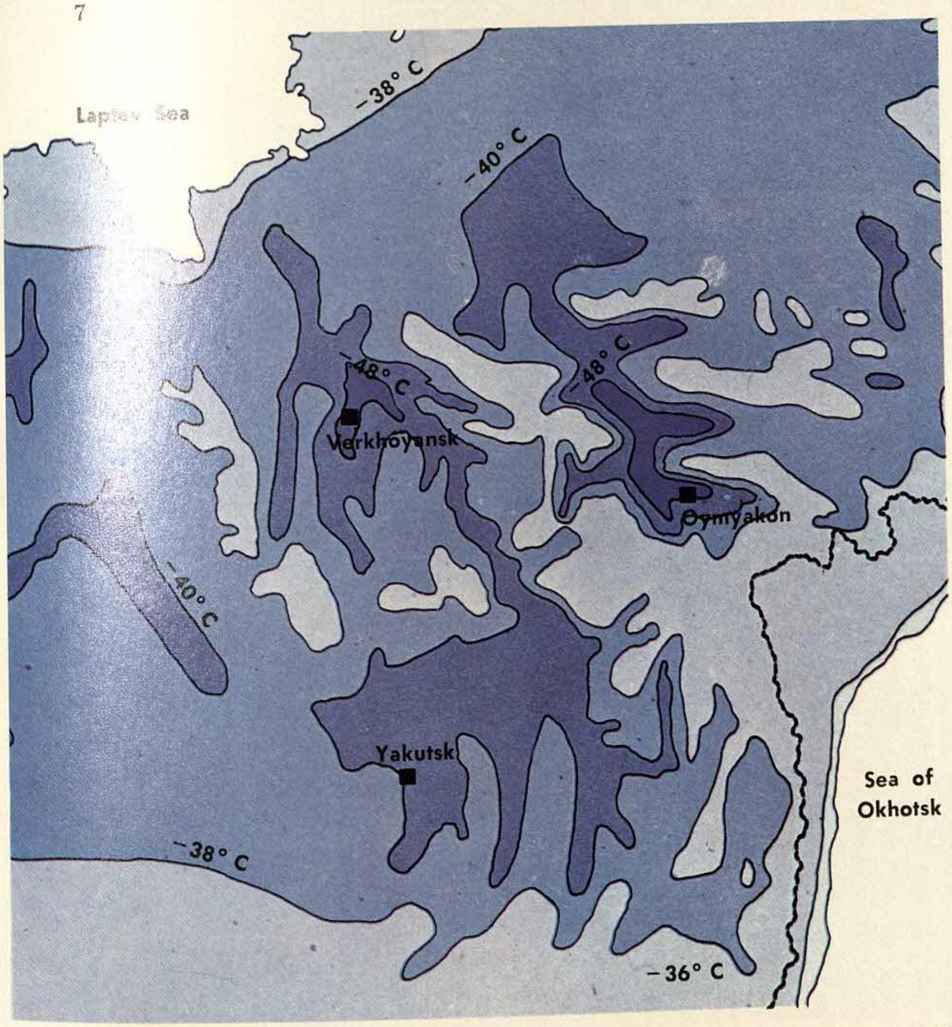


EXTREME COLD — Extremes of temperature characterize the continental type of climate, found in the interior of the larger land masses. This effect is accentuated when mountain ranges block off winds that might cool the region in summer or warm it in winter.

A temperature of −73° C (about −100° F) was recorded at Verkhoyansk in northeastern Siberia, where summer temperatures of 38° C (about 100° F) have also been recorded. Verkhoyansk lies between two mountain ranges, in a north-facing valley where air stagnates.

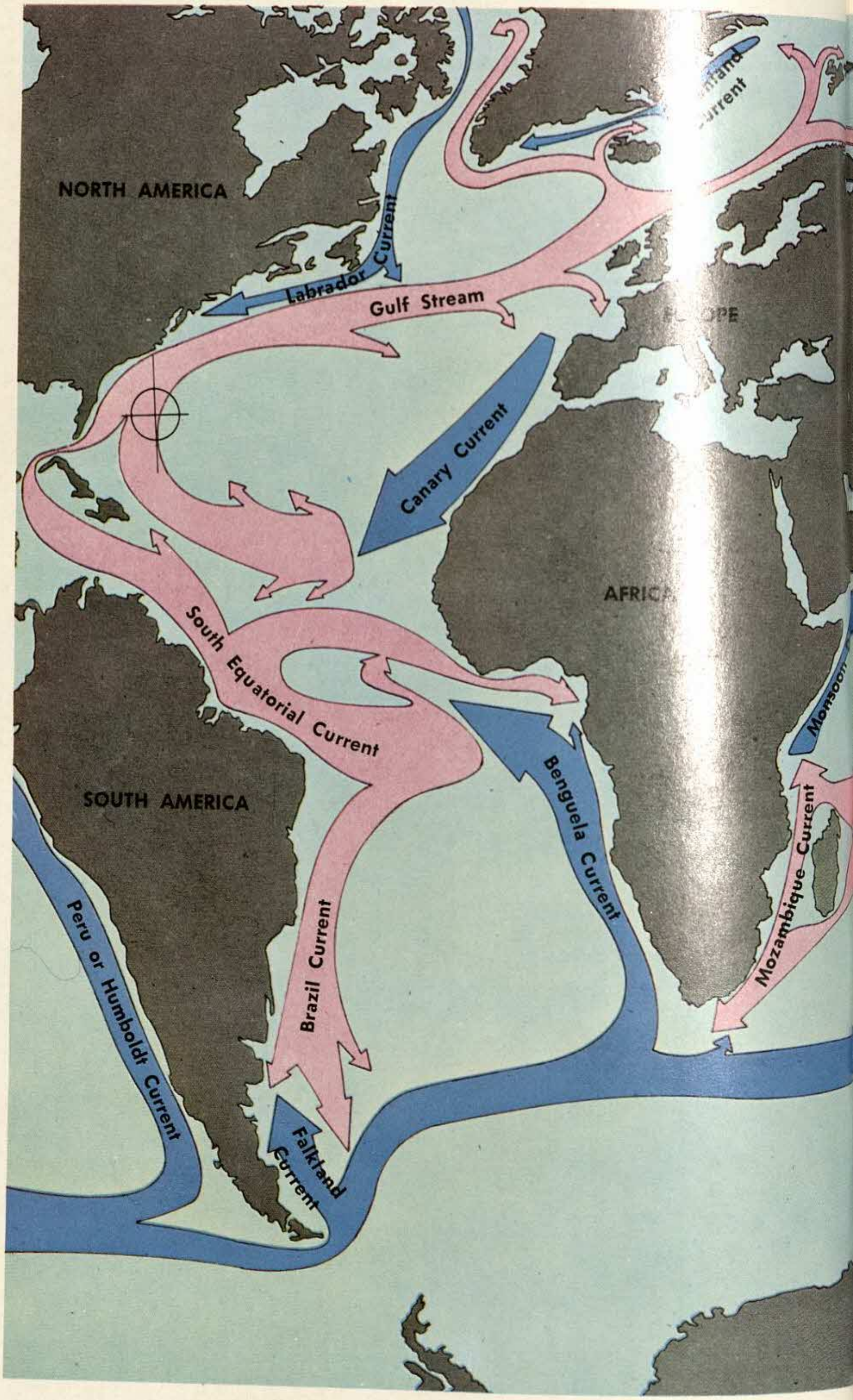
This map shows the location of Verkhoyansk, Oymyakon, and Yakutsk. In all three places the average January temperature is below −50° C (−58° F). This region would be warmer in winter if mountains did not block off the flow of relatively mild winds from the North Pole.

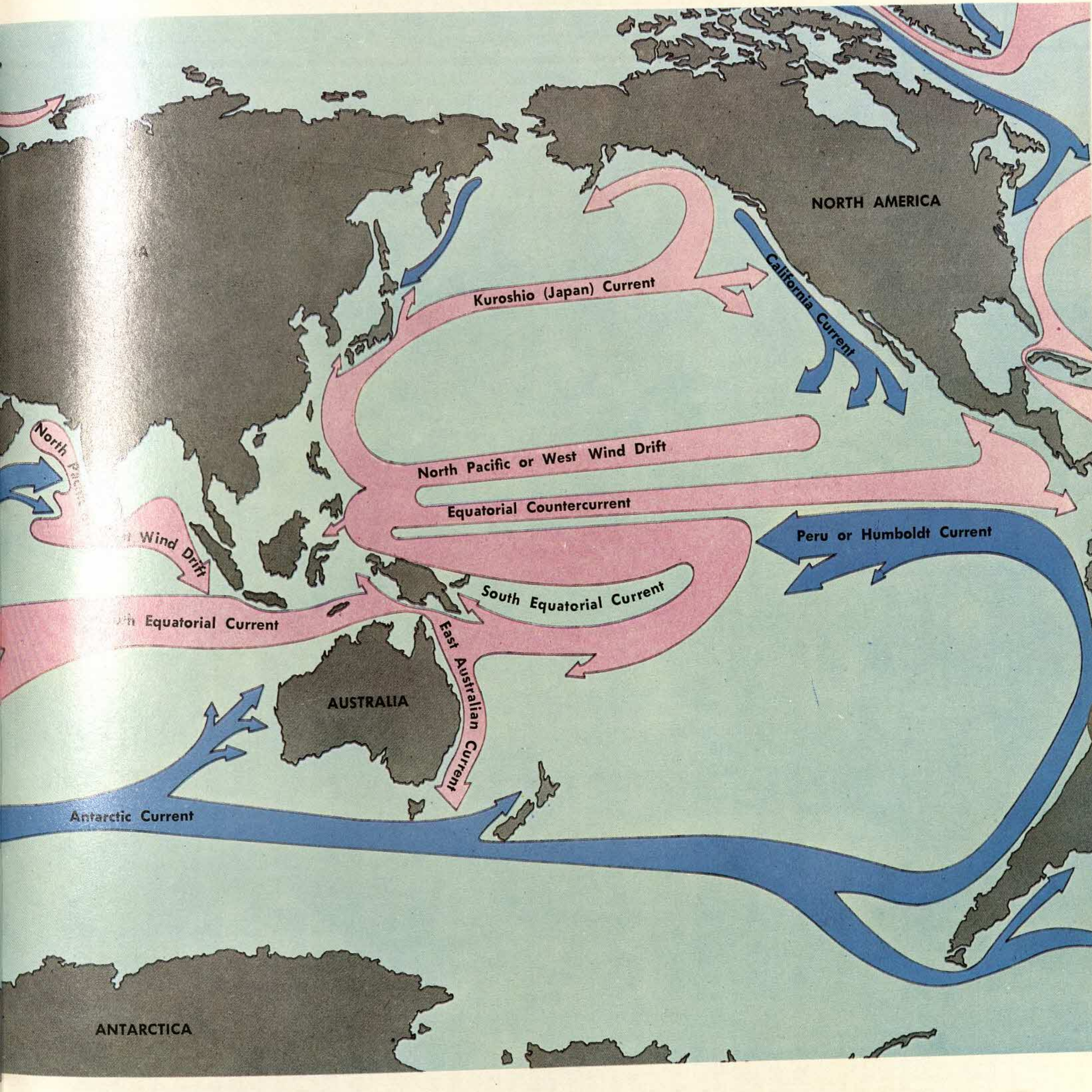
THE INFLUENCE OF MARINE CURRENTS—Two thirds of the Earth's surface is covered with water. Over this part of the Earth the winds blow freely and consistently. These winds cause the marine currents that resemble great rivers flowing through the sea. The most important marine currents are shown on this map; warm currents are shown in pink and cold currents in blue.

The Antarctic Current that circles the Earth at the latitude of 48°–50° south is caused by the forceful and consistent winds called the "roaring forties." These winds were important to mariners in the days of sailing ships. The current itself has little effect on climate because it remains at the same latitude as it flows around the Earth.

More significant is the Peru Current, which carries cold water from the southern latitudes north along the coast of South America. This current makes the climate of western South America colder than it would otherwise be.

The most important of all the marine currents is the Gulf Stream, which carries warm water from the Gulf of Mexico and the Caribbean Sea north and east across the Atlantic to modify the climate of northern Europe.





NORTH AMERICA
Kuroshio (Japan) Current
California Current
North
Wind Drift
North Pacific or West Wind Drift
Equatorial Countercurrent
Peru or Humboldt Current
South Equatorial Current
Equatorial Current
East Australian Current
AUSTRALIA
Antarctic Current
ANTARCTICA

THE ATMOSPHERE | its structure and study

Meteorology—the study of the atmosphere and atmospheric phenomena—has only recently been considered a true science and taken its place as a branch of Earth science. This is due partly to the fact that man has been studying and navigating the air for a comparatively short time.

1

THE COLLECTION OF DATA ON THE GROUND—The photograph shows a typical ground meteorological station. The instruments are generally placed in a small hut that is painted white so that the interior will not become excessively hot in the sunlight. The walls are louvered to permit free circulation of air inside the hut. The data are registered on a tape.

A BRIEF HISTORY

Actually the weather has been a concern of first-order importance to man since before the dawn of civilization. Fragments of very early writings indicate this concern, and numerous ancient religions had deities associated with various weather phenomena. Aristotle (384–322 B.C.) wrote the earliest systematic treatise on meteorology, the famous *Meteorologica.* Theophrastus, Aristotle's pupil, also wrote on winds and weather signs. However, during the next two millennia meterological study scarcely progressed beyond the point to which it had been carried by Aristotle, in spite of a number of treatises on the subject.

The development of meteorology as a science awaited the invention of instruments by which the primary physical elements of weather could be measured. In 1607, Galileo invented the thermometer, which made possible the measurement of air temperature. Then, in 1643, Evangelista Torricelli invented the barometer, which permitted the measurement of air pressure. These developments, coupled with the establishment of elementary physical laws of gases, liquids, and solids, gave impetus to atmospheric study.

The first meteorologists were probably mariners. Traveling around the world in ships, they prepared charts of the trade winds and monsoons. In 1735, George Hadley attempted to explain the trade winds, including in his explanation some accounting of the effect of the Earth's rotation on atmospheric winds.

The physical basis of modern weather science was firmly established when Antoine Lavoisier, in 1783, determined the true nature of air and when John Dalton, in 1800, explained the variations in the moisture content of air and the relation between the expansion of air and atmospheric condensation.

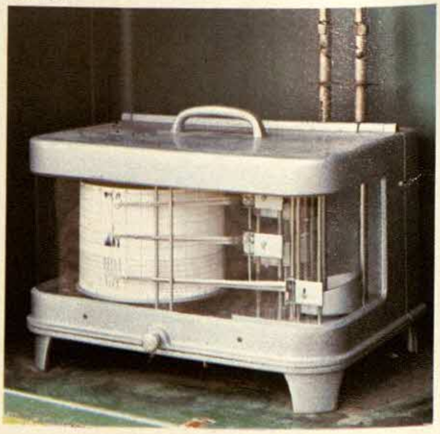
Developments during the nineteenth century were limited, for the most part, to the field of synoptic meteorology—that is, to the organization of networks of weather observing stations, to the preparation of daily synoptic charts, and to the institution of modern weather-forecasting techniques.

Prior to 1900, meteorological studies were restricted generally to the lower levels of the atmosphere. Man's first flight in a balloon occurred in the eighteenth century, of course, but not until the late nineteenth century did he begin to explore the upper atmosphere. With the beginning of the twentieth century, he began an increasingly intensive exploration of the upper air, using instrumented free balloons. L. P. Teisserenc de Bort, a French innovator, released 581 balloons into the atmosphere; these balloons were equipped with lightweight, recoverable instruments for measuring the temperature and pressure in the atmosphere to a height of about 14 km (45,000 ft). De Bort published the results of his research in 1904.

As time passed, scientists began to use improved balloons, some of which transmitted their instrument records by radio; the latter reached altitudes in excess of 40 km (130,000 ft). Man also used airplanes to probe the atmosphere at somewhat lower levels. Following World War II, he began to use rockets and weather satellites to investigate the Earth's atmo-

2

ANEMOGRAPH — This instrument registers wind velocity and direction on a chart. The top and middle pointers register wind direction while the lowest pointer registers wind velocity.



spheric envelope to the very fringes of outer space. Instruments were used to chart the atmosphere, and differences in such properties as air temperature and density became quite evident at different altitudes.

A series of rocket observations, begun in 1946 described the atmosphere more precisely than ever before; moreover, they provided substantial information concerning the solar radiation that is absorbed in the upper atmosphere. Solar radiation in the very short wave (ultraviolet and x-ray) region of the electromagnetic spectrum has an important effect on the atmosphere, especially the upper parts. Satellites, which can observe the sun continuously, have also been useful in the study of solar radiation. In addition, they have played very significant roles in the science of weather forecasting.

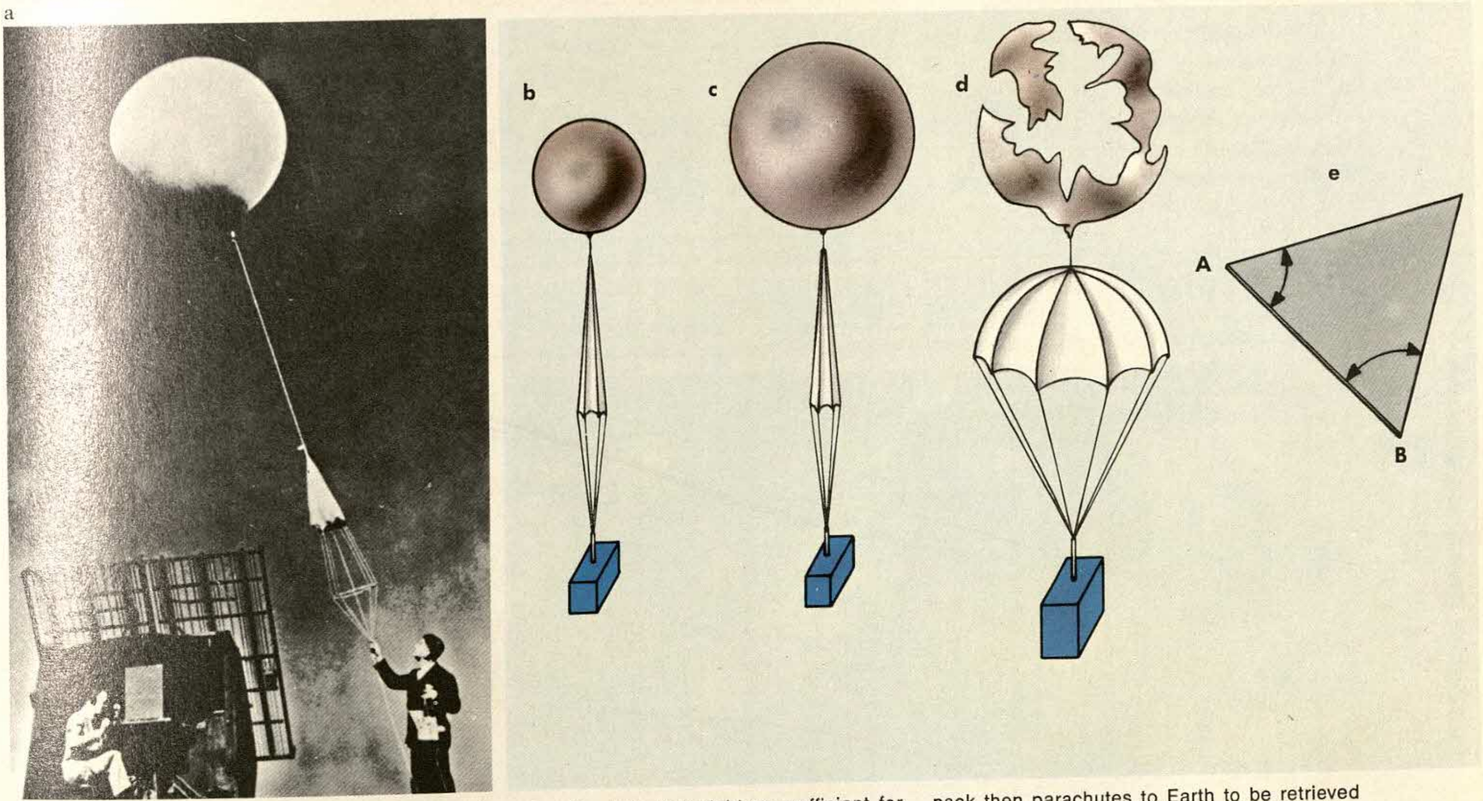
THE VARIOUS STRATA OF THE ATMOSPHERE

Scientists have divided the atmosphere into strata. The troposphere is that stratum of the atmosphere up to approximately 10 km (about 6 mi). This is the stratum in which man lives, in which clouds form, and where weather as man sees it occurs. In this stratum, temperature decreases with altitude.

The stratosphere covers the area between approximately 10 to 35 km (about 6 to 22 mi). The temperature here is higher than in the troposphere, but is relatively constant at all levels.

The mesosphere covers a height of approximately 35 to 75 km (about 22 to 47 mi). Ozone is formed in this stratum, and temperature decreases with height.

3



THE FLIGHT OF A SOUNDING BALLOON—Meteorological stations based on the ground or aboard ships can make simple weather readings by using the sounding balloon (Illustration 3a), a small balloon inflated with hydrogen. Beneath it, attached by a nylon cord, is a small parachute, and beneath this is the sounding equipment. The parachute protects the equipment from damage in landing.

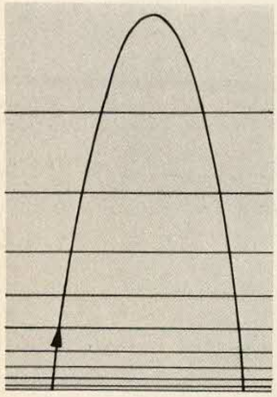
The sounding equipment is light in weight and can be carried to an altitude of 15,000 to 20,000 m (about 50,000 to 65,000 ft). The instrument pack contains batteries and a radio transmitter, which at frequent intervals transmits data regarding pressure, temperature, and humidity.

The instruments attached to sounding balloons are not as sophisticated as some of those placed in ground meteorological stations, but the data they yield are sufficient for meteorological predictions. Unlike a ground station, the instrument pack does not contain an anemograph. Since the radio transmitter is carried by the balloon, the direction and velocity of the wind can be deduced from the position of the balloon.

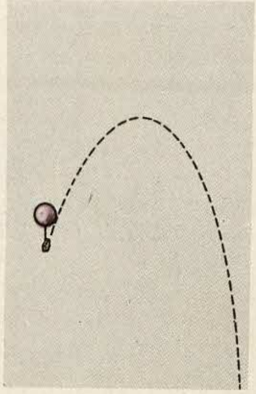
Illustration 3b shows the balloon at launching. Its diameter is small because the hydrogen is under ground-level atmospheric pressure and has not expanded. In Illustration 3c, however, the balloon has risen and expanded to a larger volume. The balloon rises rapidly to the desired altitude and remains there carried randomly by the wind, from five to ten hours. Finally, the low temperatures and pressures of the high altitudes, together with the sun's radiation, weaken the balloon material until it breaks (Illustration 3d); the instrument pack then parachutes to Earth to be retrieved and reused. Illustration 3e shows the technique used to determine the balloon's position. Each of two radiodirectional stations located at **A** and **B** takes a bearing on the direction of the balloon. Given the distance between the two stations, a cross bearing pinpoints the position of the balloon; additional cross bearings indicate the direction in which it is moving.

In many cases, when a long distance flight is not required, the data from a single station are correlated with the data on the altitude of the balloon. It is then possible to calculate the distance of the balloon by knowing the height of the radio-localized antenna required to clearly receive the radio signals transmitted from the balloon.

4a



4b



A MORE MODERN METHOD—The use of meteorological rockets has become more and more prevalent over the past several years. These rockets are capable of reaching altitudes as high as 200 km (about 125 mi). Meteorological rockets are 1 to 2 m (about 3 to 6 ft) long. They contain radio transmitters, and carry enough fuel to reach their assigned altitudes.

Illustration 4a shows the almost vertical trajectory of a meteorological rocket. Illustration 4b shows a type of rocket called a sky hook. A balloon carries this type of rocket to extremely high altitudes; the rocket thereby avoids the braking action of the lower atmosphere.

The ionosphere ranges from a height of approximately 75 to 550 km (about 47 to 340 mi). In this stratum, the shortwave radiation of the sun has a dominant effect. Conduction of electricity is excellent, due to the presence of a large number of charged ions and free electrons. Temperature increases with height in this stratum.

Knowledge of conditions in all strata of the atmosphere has aided meteorologists in understanding the weather in the troposphere. For example, it is known that high-altitude changes affect conditions at ground level.

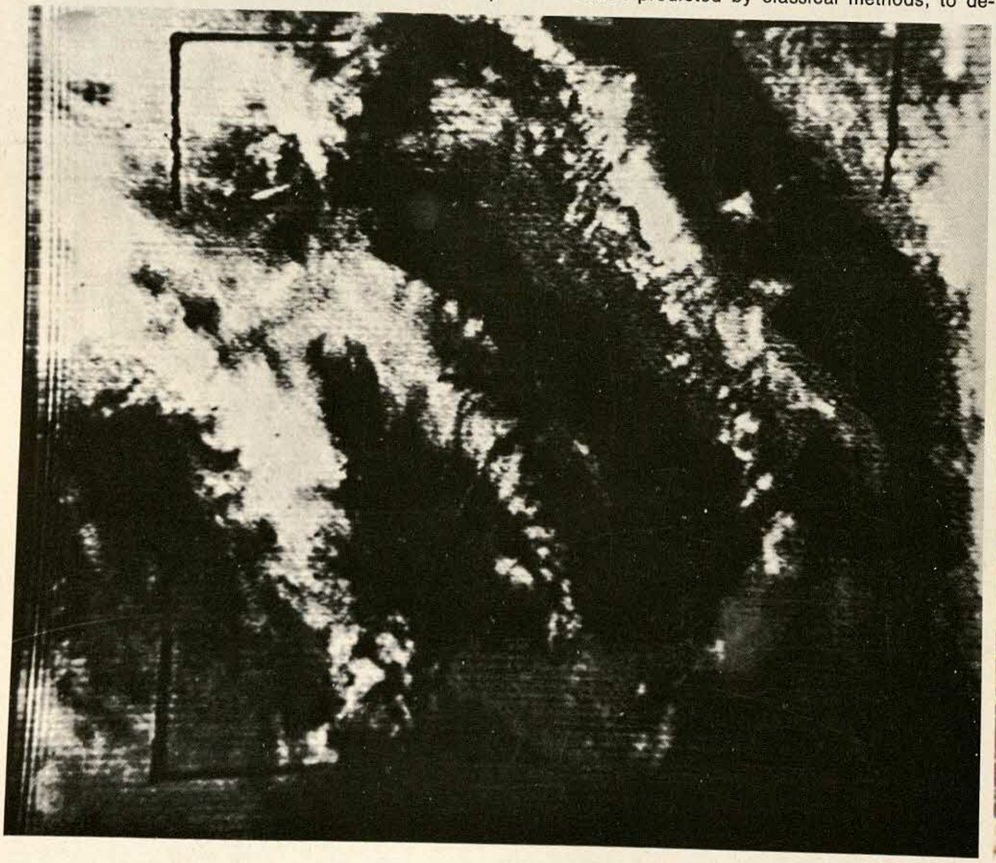
In the first quarter of the twentieth century, it was discovered that the way in which radio waves behaved near the Earth was determined by the electrical composition of the ionosphere. Radio waves beamed horizontally continued horizontally, but those beamed up were reflected back to Earth by the electrically charged particles in the ionosphere. Once this was known, radio wave techniques for measuring ionospheric properties were developed.

The Earth's magnetic field was found to be affected by conditions in the ionosphere. Electrical activity and changing air motions at this height create high-altitude electrical currents that can cause changes in the Earth's magnetic field.

With the advent of astronautics, the study of the upper atmosphere has been

5a

METEOROLOGICAL SATELLITES—Today meteorological satellites are used extensively to collect data on the visible cloud cover and the infrared radiation of the Earth. From photographs like this (Illustration 5a), it is possible to determine, at least in part, the progress of the winds; to visualize the meteorological situation predicted by classical methods; to deduce the accuracy of the predictions and to improve them for the future. Illustration 5b shows a type of meteorological satellite used to transmit photographs to Earth.



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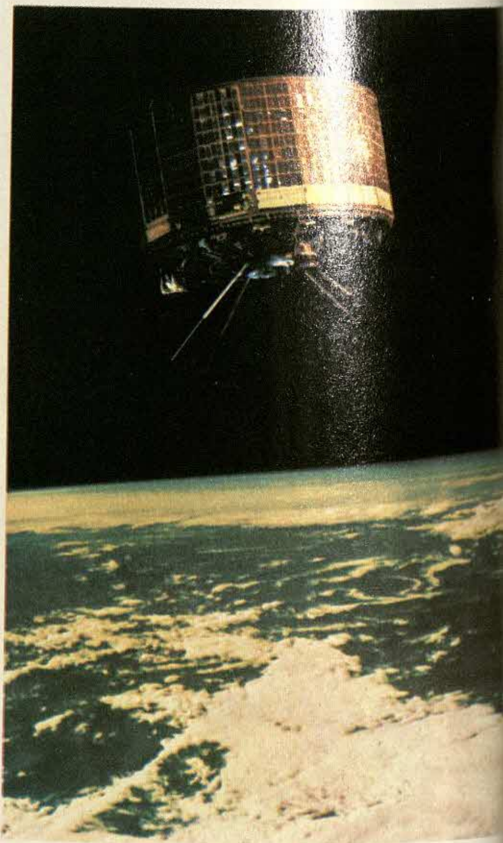

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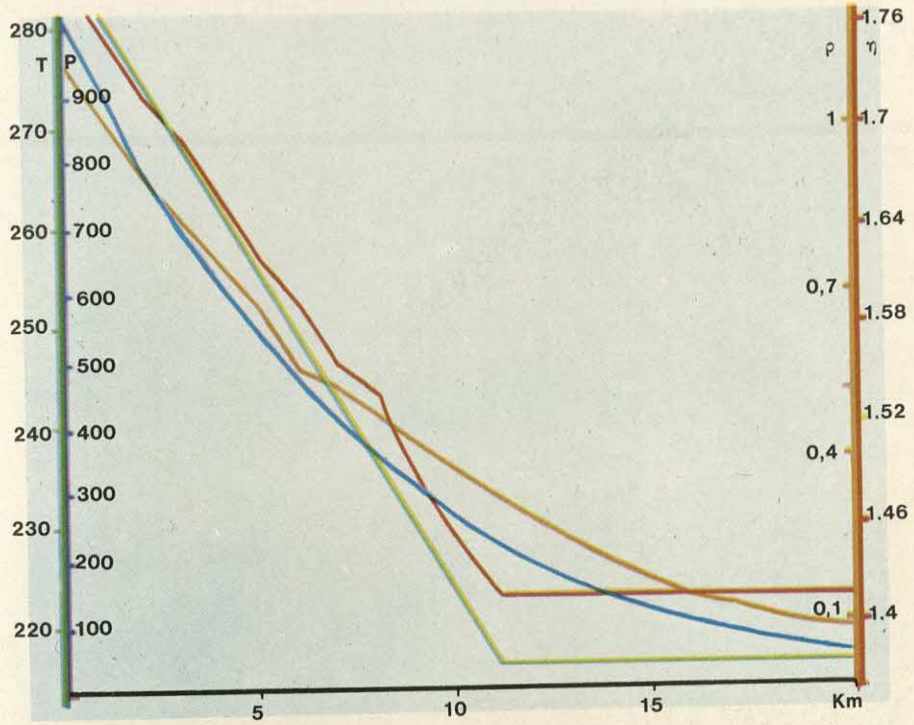


PRESSURE-TEMPERATURE-DENSITY CHART —The chart covers the altitude to 20 km (about 12 mi) and is based on a formula that approximates the course of the curve. The temperature **T** is given in ° K, the pressure **P** in millibars, and the density ρ in kg/m^3.

vastly extended. The Earth is at present being orbited by a great number of artificial satellites circling at altitudes from hundreds to thousands of kilometers. Although the atmosphere is extremely rarefied at these altitudes, it still produces a definite braking effect on the satellites. Knowledge of the conditions in the upper atmosphere helps scientists calculate the orbit of a satellite precisely.

The upper atmosphere must also be understood to predict accurately the trajectories of rockets. Such trajectories can be deviated by varying air densities in the atmosphere. If the trajectory of a test rocket is not precisely calculated, untold diplomatic or military problems could result.

Despite tremendously increased knowledge of the atmosphere, meteorologists have much to learn before their understanding is complete. As yet, no precise formula exists for the measurement of air density at different altitudes. A precise hypsometric formula would allow the construction of a graph plotting the curve of air densities at various altitudes in the atmosphere.

METEOROLOGICAL INSTRUMENTS

The study of the atmosphere has now reached the stage in which meteorologists can speak of three generations of meteorological instruments. First-generation instruments are the well-known ones used for collecting elementary weather data—barometers, anemometers, and so forth. Although these instruments have been superseded by more sophisticated devices, they are still useful in many instances. They are inexpensive, function automatically, and their data can be transmitted to distant points. They can be placed in great numbers along a certain circuit, and are used to compile weather charts.

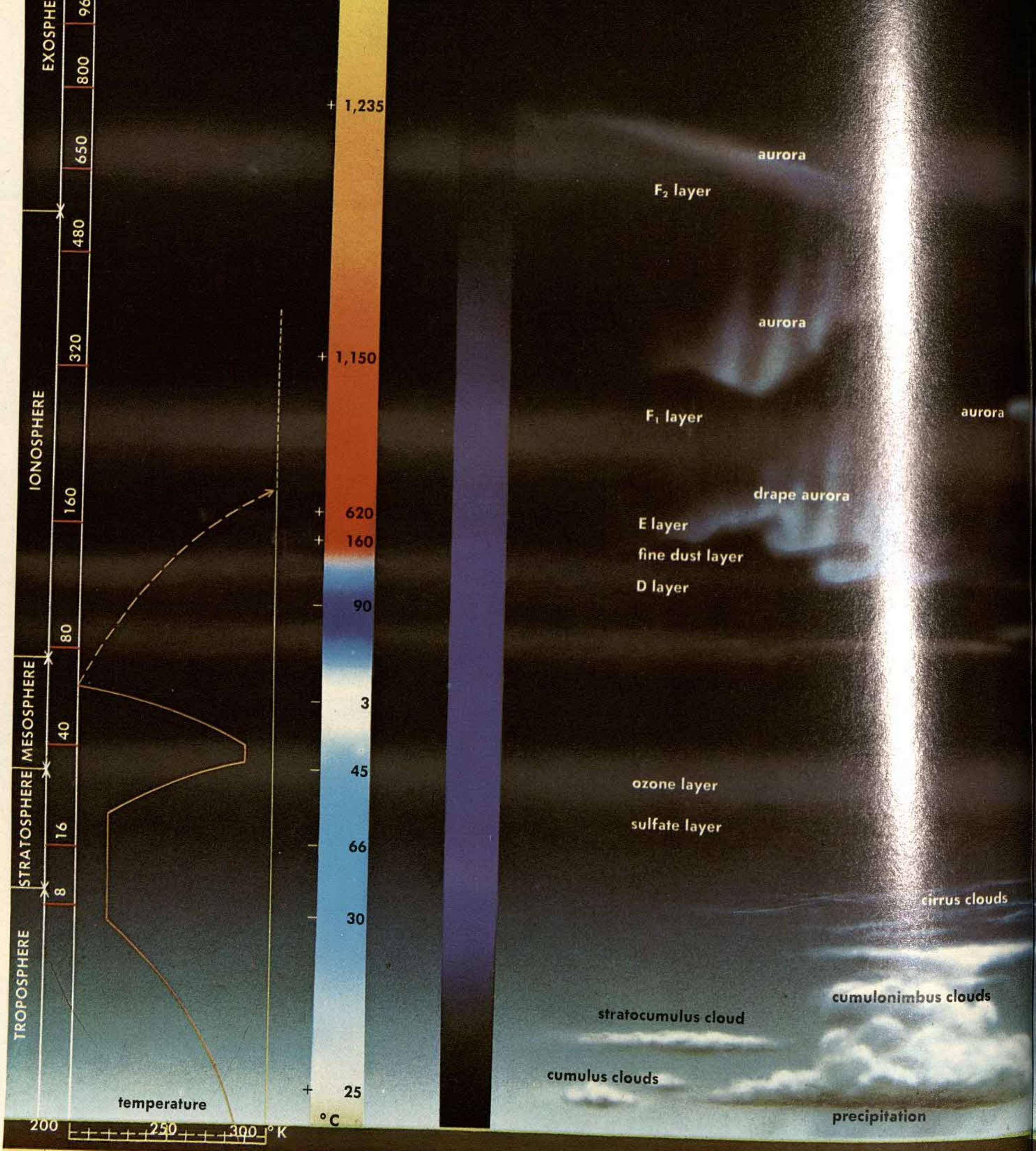
Weather radar is an example of modern devices used to supplement data acquired by use of first-generation weather instruments. Weather radar is widely used in the observation of the structure and motion of clouds and storms.

Second-generation meteorological instruments are those carried aloft by unmanned balloons. These instruments, light in weight, transmit their data by radio to the ground. As meteorological balloons travel, they also transmit their position to a ground station. While the winds carry the balloon indiscriminately, the ground tracking station is aware of its position.

Third-generation meteorological instruments are mounted in artificial satellites. Some of these instruments take and transmit pictures of the cloud blanket covering the Earth. Such photographs reveal wind shifts and are helpful in predicting hurricane formation.

Artificial satellites also carry instruments such as the radiometer, a device which analyzes the Earth's thermal behavior (infrared radiation), and the way it is influenced by the atmosphere. This analysis is one of the most important aspects of present-day meteorology.

Third-generation meteorological instruments are the logical complement to those of previous generations. While the earlier instruments yield data that are immediately interpreted for direct weather prediction, the third-generation instruments are designed to furnish meteorological data used in basic atmospheric research.

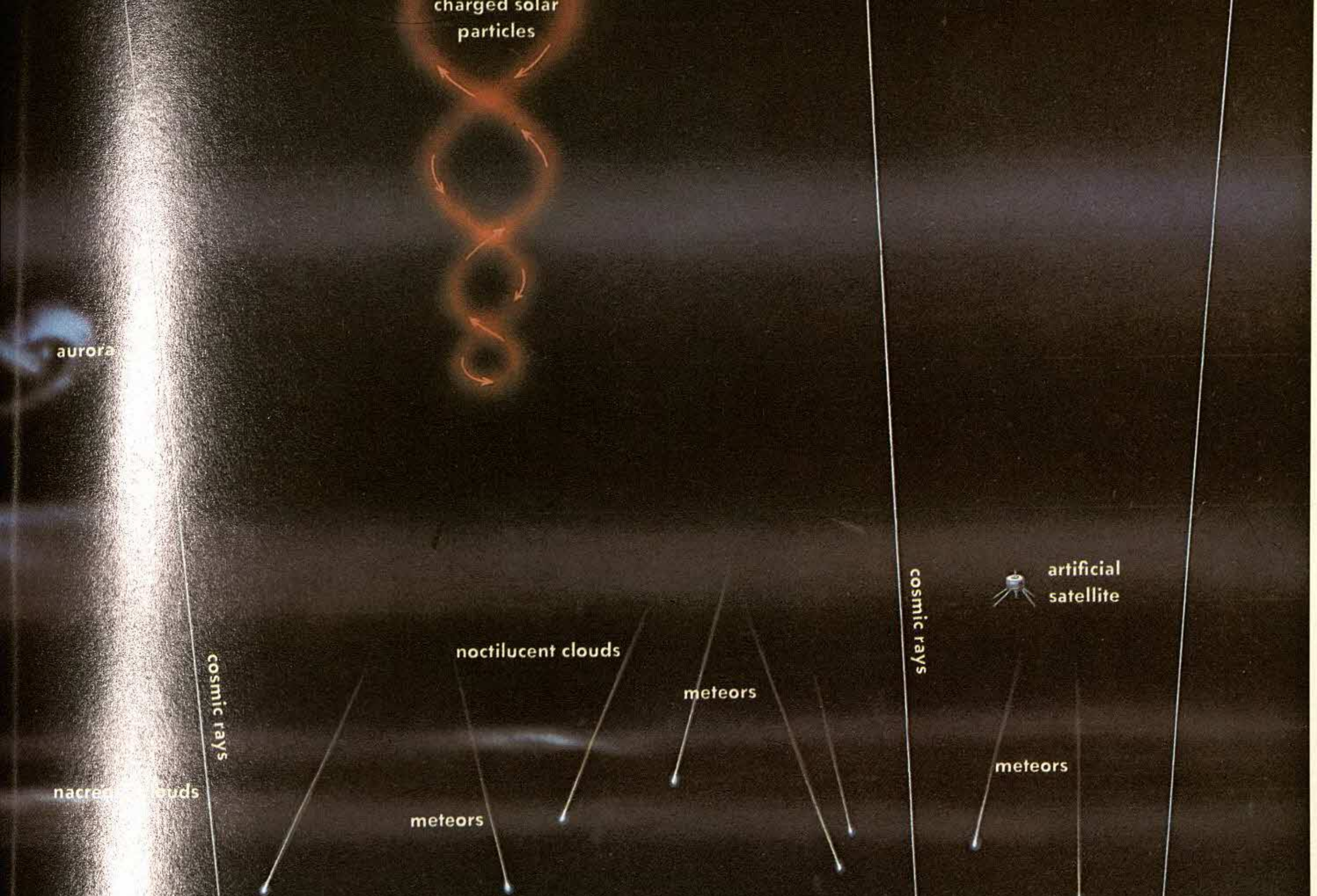


THE EARTH'S ATMOSPHERE—This illustration projects a great deal of information about the structure of the atmosphere and the phenomena characteristic of the different strata. The troposphere is the stratum closest to the surface of the Earth, the stratum in which most ordinary weather changes occur. Immediately above the troposphere is a thin layer of air, the tropopause, which is characterized by a temperature inversion—that is, an increase in temperature. In effect, the tropopause separates the troposphere from the next higher stratum, the stratosphere. In this layer, vertical mixing of air is very slight. The temperature of the stratosphere is relatively constant. At an altitude of about 30 to 50 km (about 20 to 30 mi), there exists a region of relatively high temperature and high ozone content. The ozone in this layer is formed as a result of the action of ultraviolet light from the sun on the molecular oxygen of the atmosphere. Below the ozone layer is a layer containing sulfate molecules, which are not found anywhere else in the atmosphere.

At higher altitudes, the temperature increases, declines, then increases again toward the mesosphere, which is distinguished from the stratosphere chiefly by temperature differences.

Above the mesosphere is the stratum known as the ionosphere, the part of the atmosphere characterized by the presence of a large number of electrically charged particles (electrons and ions). Certain layers of the ionosphere (designated as the D, E, F_1 and F_2 layers) reflect radio waves back to Earth. A layer of very fine dust exists in the region between the D and E layers.

Each stratum of the atmosphere is characterized by certain phenomena. The troposphere is the layer in which most clouds form and in which most meteorological data are collected. Cumulus, altocumulus, stratocumulus, cumulonimbus, and cirrus clouds are common in this part of the atmosphere. The stratosphere is



noted for its constancy of temperature and its lack of turbulence. Most meteors burn up in the mesosphere after having begun to glow in their passage through the ionosphere. Noctilucent clouds, which occur rarely, may be seen at an altitude of about 80 km (50 mi); these clouds are illuminated in the night sky by the reflected light of the sun. The equally rare nacreous clouds may sometimes be seen at somewhat lower altitudes; they are also called mother-of-pearl clouds, because of their pearly luminescence.

At still greater altitudes, in the ionosphere and exosphere, the famous auroras may be observed. The auroras are of several types: the lowest are the so-called drape auroras; at higher altitudes, the arc and ray types of auroras occur. The aurora phenomenon observable in the Northern Hemisphere is called the aurora borealis or northern lights; that observable in the Southern Hemisphere is called the aurora australis or southern lights.

The exosphere and upper ionosphere are also regions penetrated by electrons and other charged particles from the sun; these particles entering the upper atmosphere move along a spiral (helical) path that is determined by the direction from which they come and by the orientation of the Earth's magnetic field.

The Earth's highest mountain, Mount Everest, rises high into the troposphere, where the air is thin. Above the troposphere, the air is clear and free of clouds.

Cosmic rays (protons, alpha particles, and the nuclei of heavy atoms) enter the atmosphere from outer space, colliding with atoms and molecules in the upper atmosphere. These collisions produce secondary cosmic rays, which infiltrate the lower reaches of the atmosphere. Cosmic radiation is responsible for transforming certain atoms in the atmosphere into radioactive isotopes of carbon (carbon-14), one substance used by scientists in making age determinations of long dead organisms.

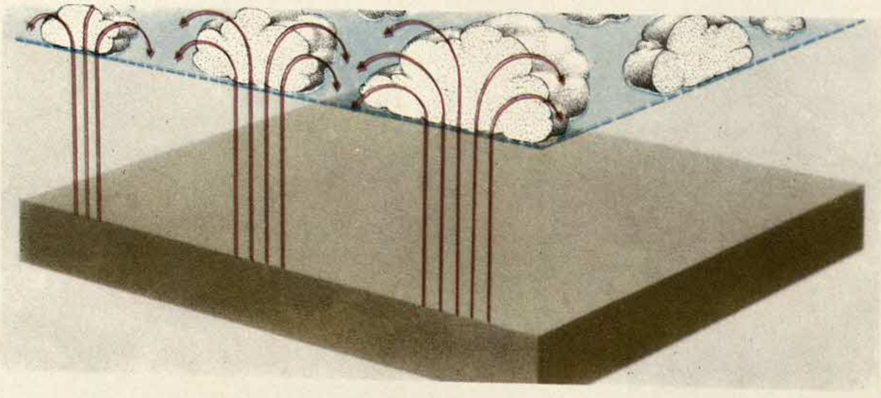
CLOUDS AND PRECIPITATION

CONVECTION CLOUDS — These clouds are formed through the effect of solar radiation as it strikes the Earth and heats it. The air in contact with the Earth is thus heated and, becoming lighter, rises. Some moisture is always contained in the rising air. The rising moist air becomes cooler as it expands and forms a cloud. When the cloud reaches a certain temperature, which is constant throughout a wide area, the droplets of moisture increase in size and turn into rain or snow.

Convection clouds form mostly during the day and in hot weather. They start as small clouds and grow successively larger to a vertical height of about 1,000 m (about 3,300 ft). At nightfall they disappear.

The arrows in the illustration indicate the flow of rising air.

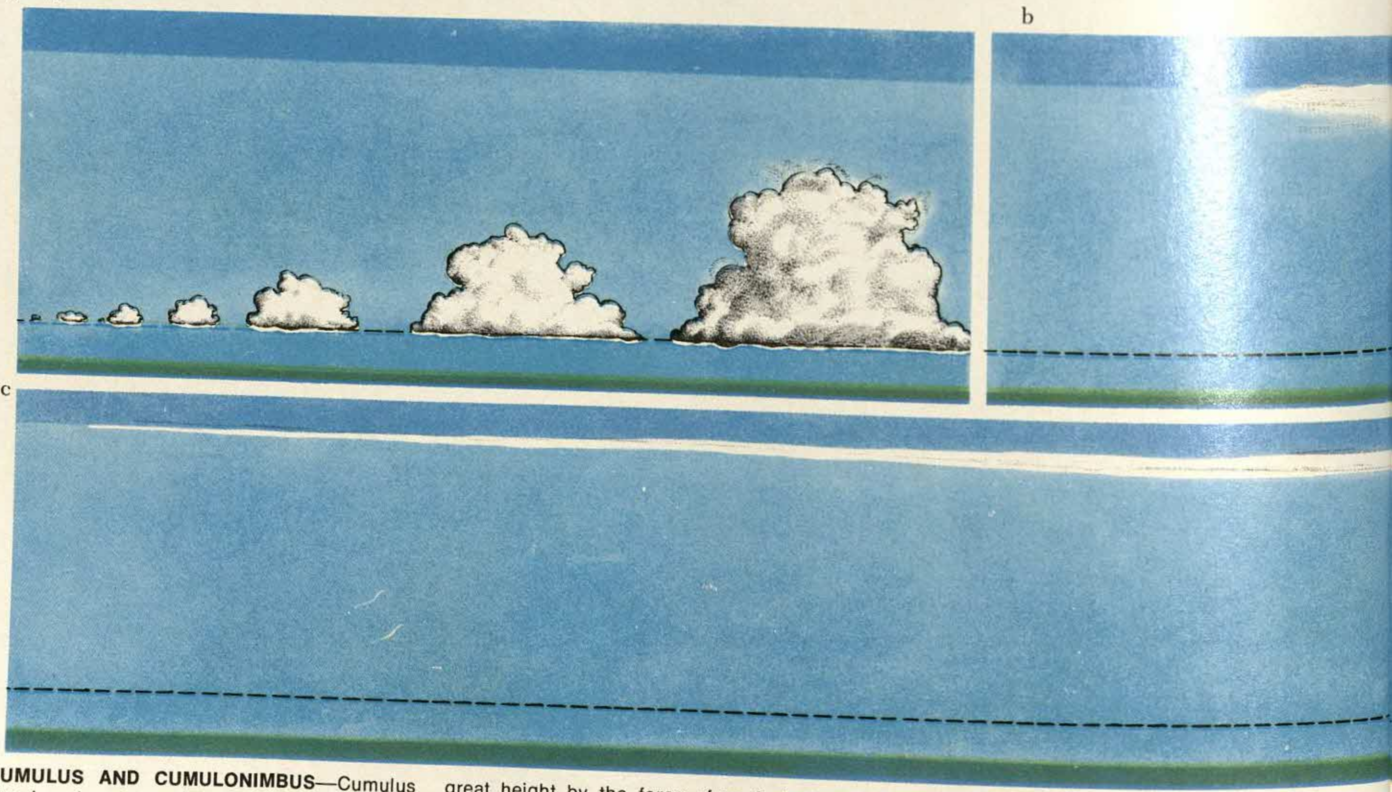
1



Although the meteorologist can do no more about the weather than anyone else, he can explain its causes. Applied meteorology is a science that attempts to predict the weather by combining two sets of data—the weather conditions at any given moment, plus a knowledge of the meteorological history of the given area in the immediate past. The latter supplies criteria by which the other data can be evaluated.

One of the factors in weather prediction is the study of cloud formations, for these are a sensitive index of weather conditions. The study of clouds is complex, and is usually limited to conditions in the immediately observable area. Certain elementary formations are basic to the science of meteorology. These classifications can be divided, subdivided, and overlapped to provide an extremely varied meteorological panorama.

2



CUMULUS AND CUMULONIMBUS—Cumulus clouds, when favored by certain atmospheric conditions, may build to a height of 12,000 m (about 40,000 ft) or more.

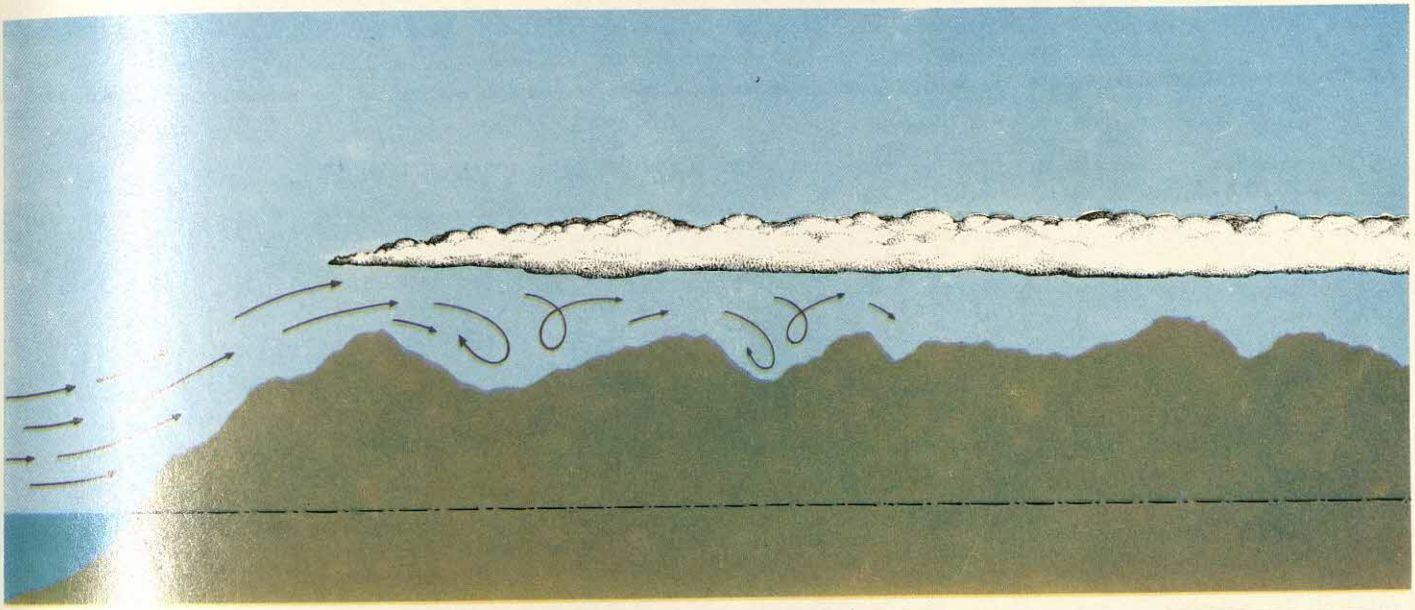
Illustration 2a shows the stages through which a cumulus cloud develops, attaining its great height by the force of vertical air currents within it. These currents may reach a velocity of 40 to 50 m/sec (about 90 to 110 mph) in the center of the cloud.

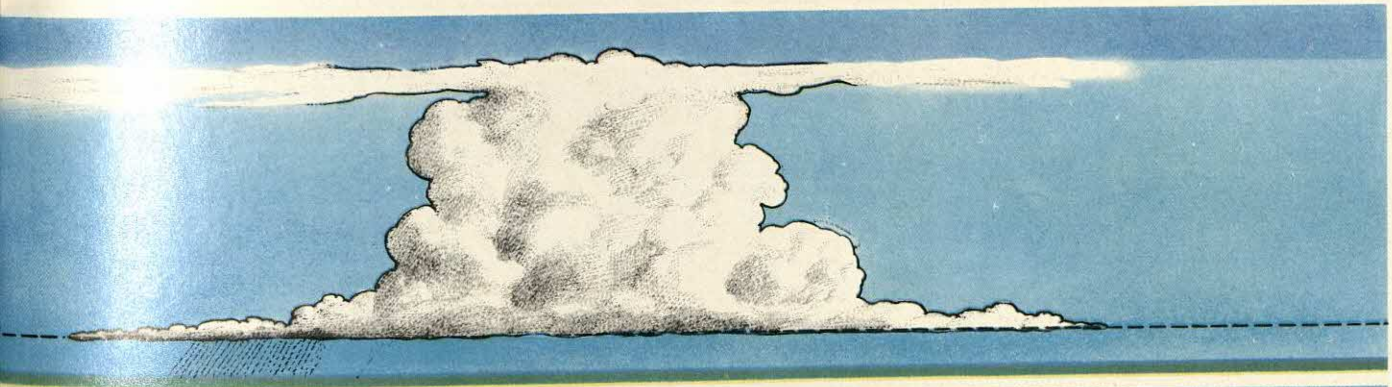
The top of a cumulus cloud is somewhat conically shaped. The bottom is determined by the condensation level. A little above this level, the temperature falls to about 0° C (32° F), supercooling the droplets of water. A bit higher, the droplets freeze, becoming ice crystals. When the water droplets or ice crystals become too heavy for the wind currents

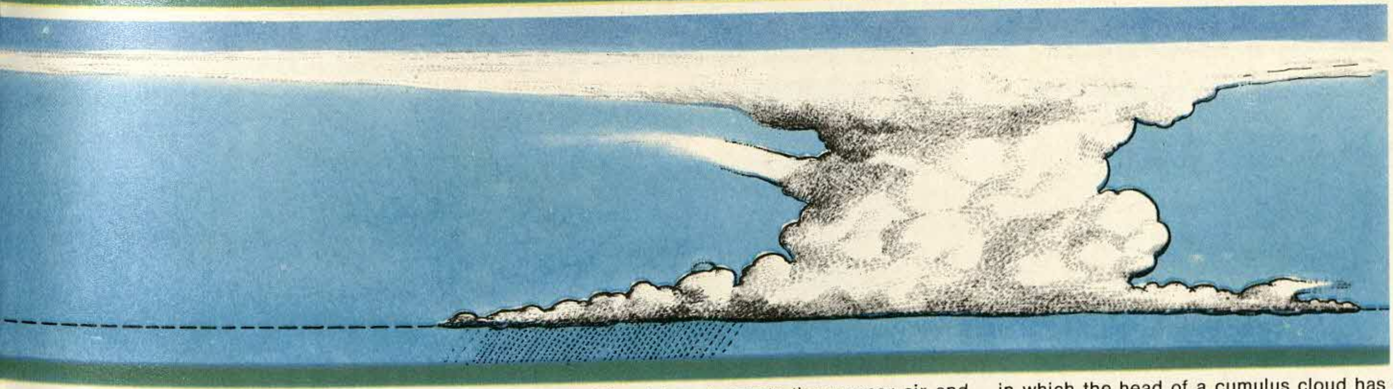
3

TURBULENT CLOUDS—The winds that move above elevations are frequently subjected to turbulence. This is caused by the movement of the air, which, where forced to follow the valleys and peaks, is scattered as it moves over the top of an elevation. Because of this, even unheated air rises above the condensation level, thus forming a cloud with a flat base in a position corresponding to the condensation level. The top of the cloud has the same rounded shapes typical of cumulus forms.

Ordinarily, these clouds are not very thick, because they are the result of turbulence, which cannot reach very high altitudes.





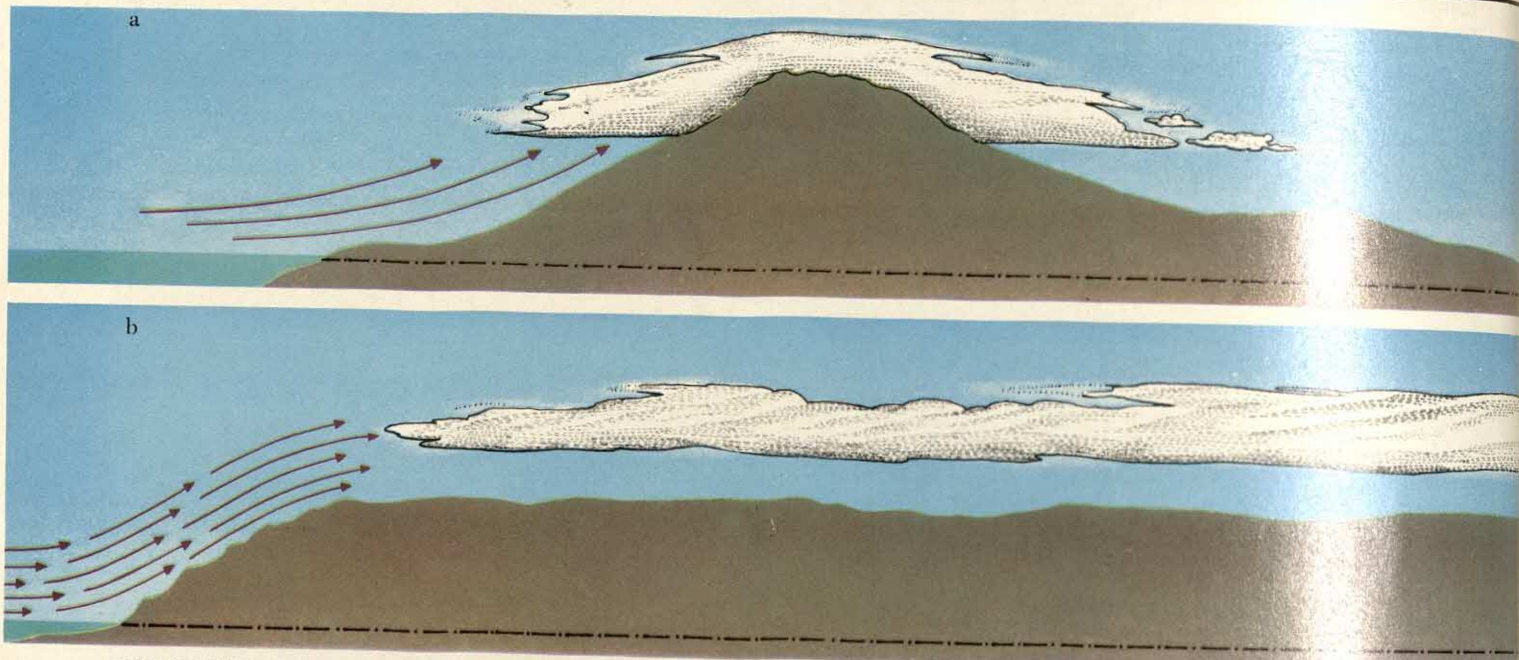


to support, they fall to the Earth as rain or snow.

Illustration 2b shows what happens when the rising air currents in the center of a cumulus cloud encounter a layer of air that is warmer than it would normally be at its altitude. The rising air meets the warmer air and can rise no further. Instead, it flares out horizontally beneath the warmer mass, forming a "cap" on the cumulus cloud. Such a cap is a stratocumulus cloud.

Illustration 2c shows an analogous situation in which the head of a cumulus cloud has expanded to form a cirrus or cirrostratus cloud, called the anvil of the cumulus.

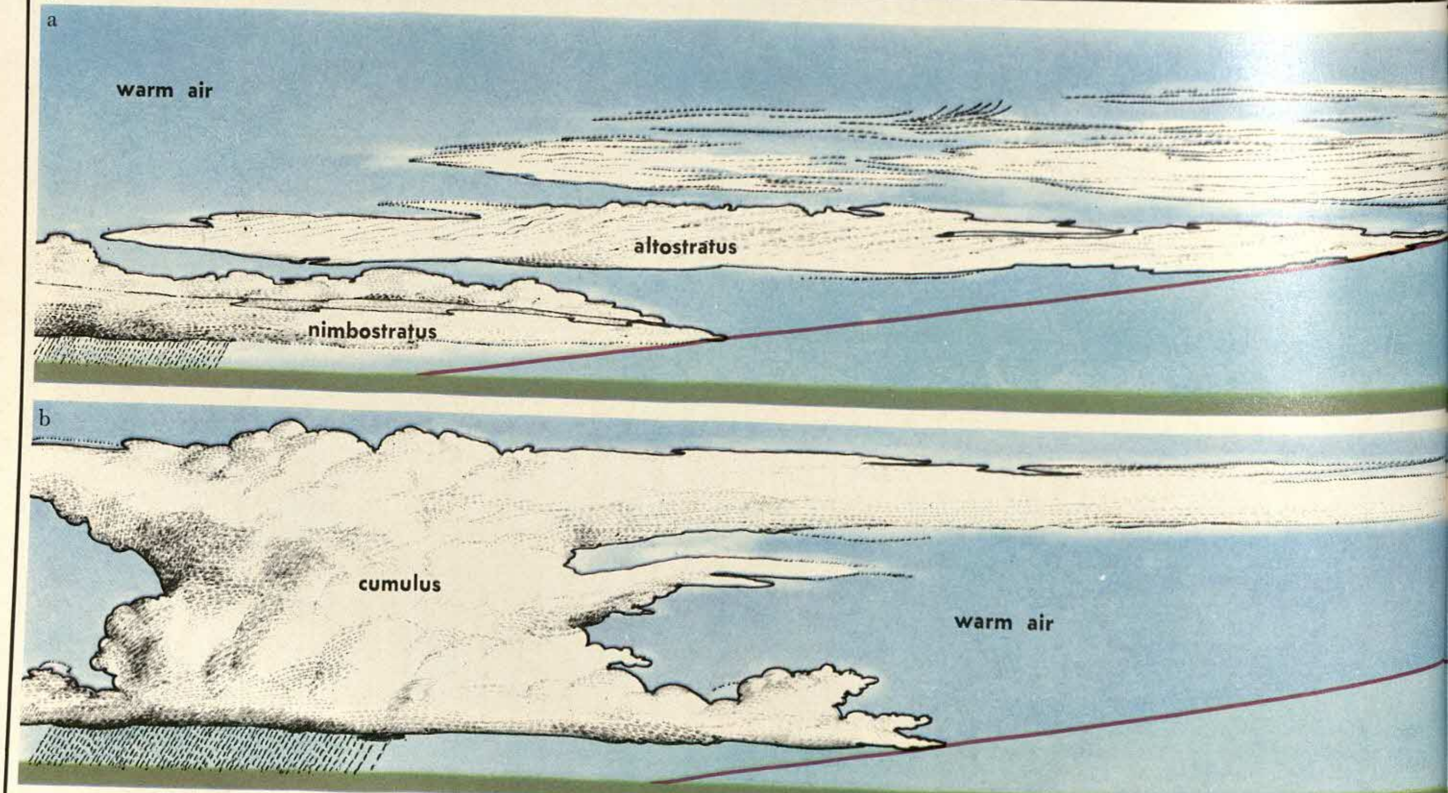
4



OROGRAPHIC CLOUDS—When an air mass is deflected upward by a mountain range, it undergoes the same cooling and condensation as any other rising air mass. It reaches the condensation level, becomes saturated, and condenses. Thus a cumulus cloud is formed that covers the top of the mountain like a hat (Illustration 4a). In some parts of the world, such as the Andes, the hot moist winds that blow off the sea create a cloud cover that is virtually permanent.

Illustration 4b shows what happens when clouds form over a high plain or plateau. These clouds, which are stratus or stratocumulus, extend for a great distance horizontally.

5



CLOUDS ASSOCIATED WITH WEATHER FRONTS—These clouds are typical of those formed by the movement of weather fronts. Illustration 5a shows a warm front running into a cold air mass. The warmer air is forced upward, even while the colder air is retreating. Rising, the air is cooled and its moisture condenses.

The type of cloud formed by this type of confrontation varies according to the altitude at which the air masses collide. At the highest part, shown on the right, cirrus clouds are formed. Such clouds are composed of fine filaments that are almost transparent. These clouds form at an altitude of 8 to 10 km (about 5 to 6 mi) and signify the arrival of a warm front.

At a lower altitude, cirrostratus clouds form. These are thicker than cirrus clouds. Next in order may be altostratus clouds, which appear opaque and homogeneous but are still comparatively thin. Altostratus clouds are har-

CLOUDS AND THEIR ORIGINS

Many types of clouds are found in the troposphere and beyond, but this article is concerned only with those clouds that are created directly by the movement of air in the tropopause and that, therefore, reflect phenomena with a direct influence on human life. The formation of nearly all clouds is associated with upward motion of the air, Some examples are:

1. Clouds produced by rising currents of moist air from air masses that have been heated by contact with the ground.

2. Clouds produced by air passing over uneven terrain, which causes turbulence.

3. Clouds caused by air masses being deflected upward by high land formations. The high ground of such formations is relatively even, so no real turbulence occurs. Such clouds are called orographic clouds.

4. Clouds that are caused by the collision of two air masses. The most common example is the collision of a cold air mass with a warm air mass.

This last category embraces clouds of several different types. Many of these give accurate clues to the forthcoming weather.

In summary, conditions leading to precipitation involve the ways in which huge masses of air thousands of feet thick are made to rise several thousands of feet in altitude. Although the rise may be either spontaneous or forced, a forced rise commonly triggers spontaneous rise. Precipitation that results from spontaneous rise of air is known as convectional. Forced ascent may be either orographic—the ascent of air in crossing a mountain barrier—or frontal—the ascent that occurs when dissimilar air masses meet.

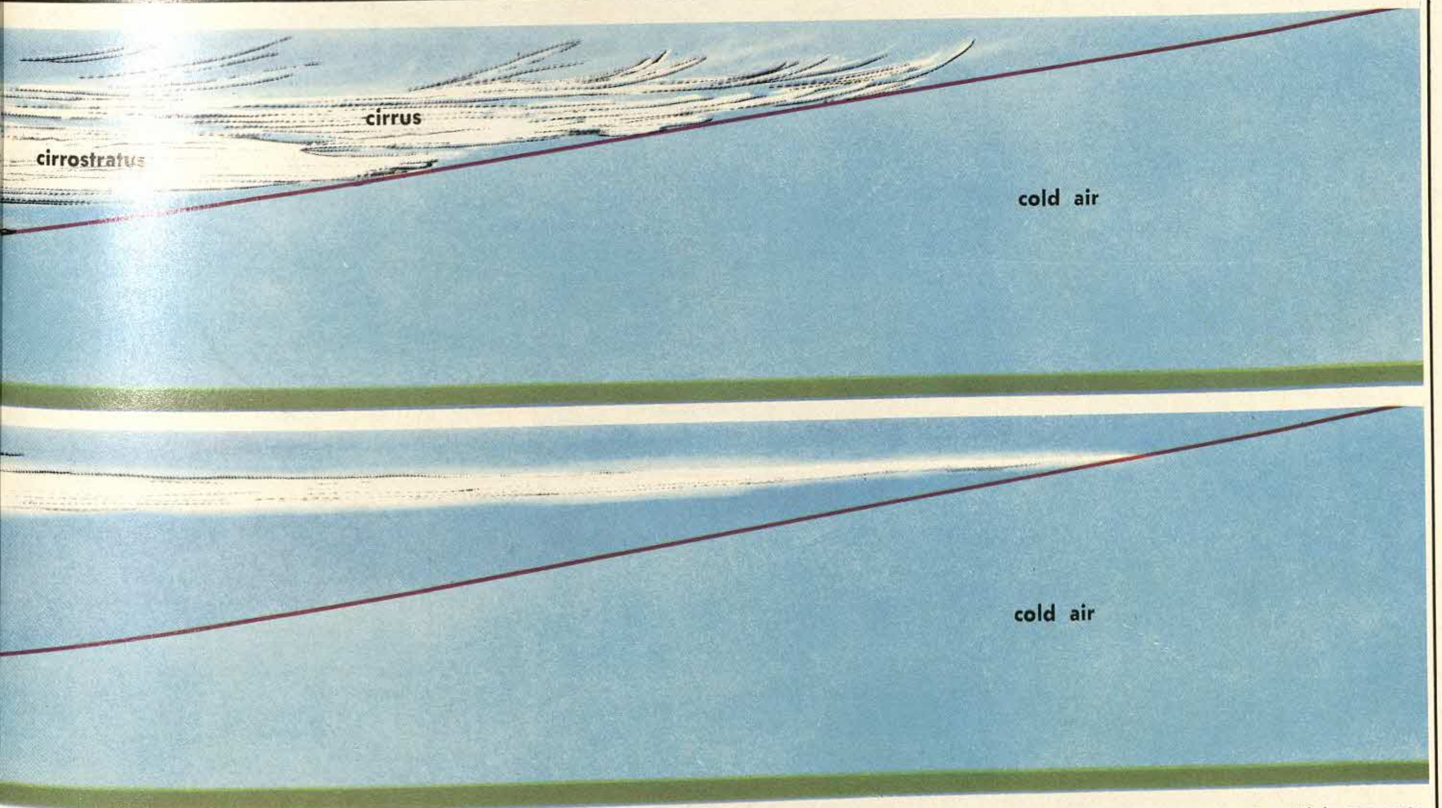
CONVECTION CLOUDS

The rising convection column is formed by the effect of solar radiation as it strikes the Earth and heats it. Becoming lighter, the air rises; and the cooled moist air expands to form a cloud. Precipitation follows. If heating of the ground by the sun is the only reason for convection, why do the thunderstorms continue to grow after the cloud shades the ground or after darkness comes? Other sources of energy also must be taken into account; one certainly is the latent heat of condensation present in the moist air and spontaneously released.

Convectional, or thunderstorm, rainfall is a dominant type in equatorial and tropical regions. The rainfall pattern is spotty because it is formed in comparatively narrow updrafts. The small storms may, however, be parts of much larger atmospheric disturbances.

OROGRAPHIC CLOUDS

When air passes over hills or mountains, the layer of air disturbed may extend to many times the height of the hills. Clouds formed in this way are stationary; they do not move with the wind at their level. In places where prevailing winds blow from an ocean across a mountainous coast, air is often made to rise thousands of feet. If the moisture content is high—and it usually is if it originates over an ocean—the dewpoint temperature is reached quickly, and further ascent of the air produces rain or snow.



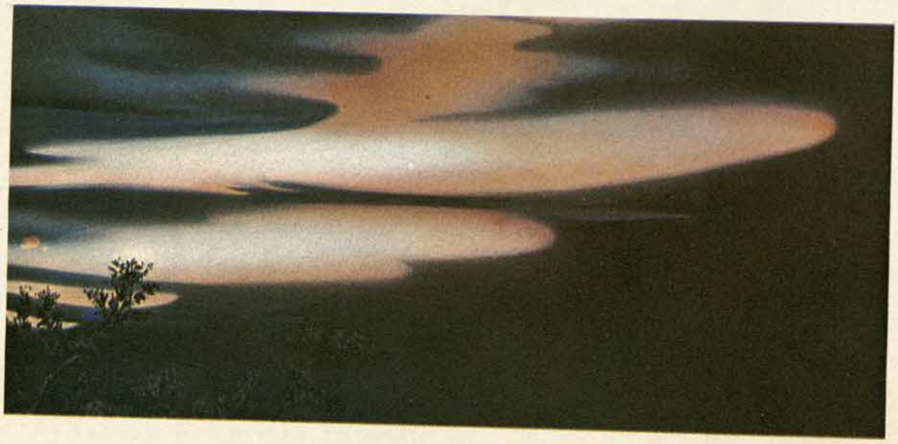
bingers of bad weather. As the lower limit of these clouds descends, nimbostratus clouds appear and the density becomes greater. From nimbostratus clouds falls rain or snow, depending on the temperature below the clouds.

All of this cloud activity occurs because of the interaction between the two air masses; once the front has passed, good weather ordinarily follows.

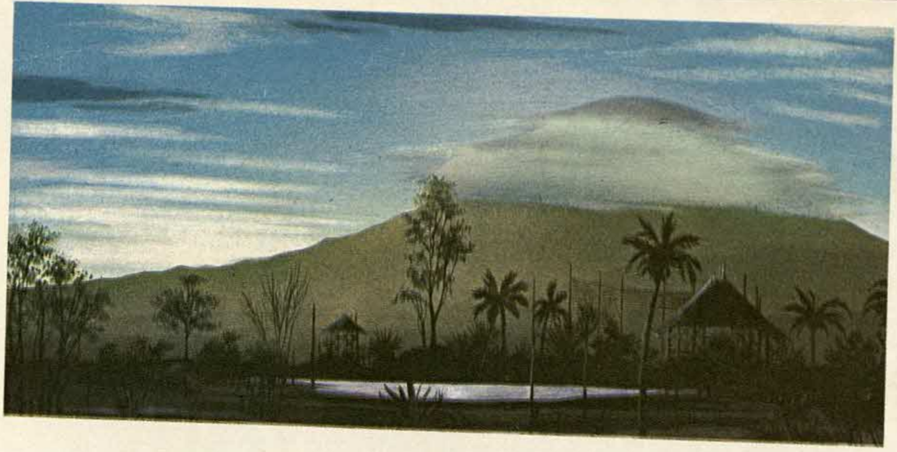
In Illustration 5b, a cold front is pushing into a warm air mass. The cold air pushes under the warm air, forcing the warm air upward and forming cumulus rather than nimbus clouds. The cumulus clouds, which are produced by the movement of the front rather than by heat from the ground, cause extensive storms. This happens frequently in spring and autumn, when masses of warm air are displaced by cold air from the north.

UNUSUAL ATMOSPHERIC PHENOMENA | spectacles in the sky

All clouds—even those that foretell an impending storm—possess awesome beauty. Certain clouds, however, either are so rare or exhibit such striking characteristics that they are more interesting as part of a general study of meteorological phenomena than as indicators of impending weather. The photographs on these pages show some extraordinary phenomena.

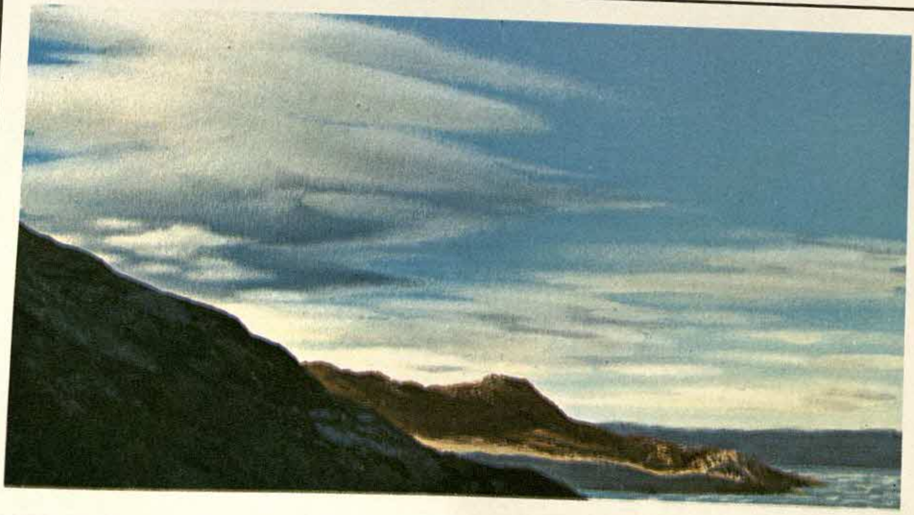


THE MARVELOUS MOTHER-OF-PEARL CLOUDS—This illustration shows nacreous or mother-of-pearl clouds at sunset. They are of the *Cirrus spissatus* type—a sort of cross between the cirrus and altostratus varieties. Of limited size, nacreous clouds usually appear isolated at very high altitudes, 20-30 km (about 12-19 mi). These clouds are formed of tiny water droplets or ice crystals which refract and diffract the light to produce the mother-of-pearl luster. They are best observed at sunset, when lighting conditions emphasize their beauty. At twilight, when lower clouds are already dark, the mother-of-pearl clouds, still illuminated by the sun, stand out against the dark sky because of their luminous iridescence.

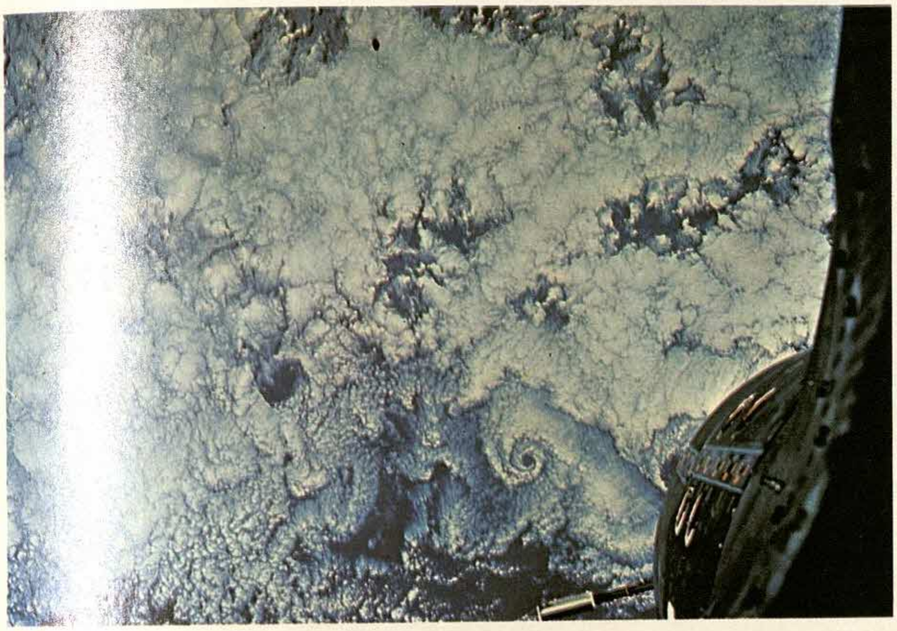


THE MOUNTAIN CAP—This volcano is covered with a beautiful orographic cloud that was produced by a relatively humid, horizontal air current of marine origin. When this moist air arrived near the mountain, it flowed up the slope, cooling as it rose. The moisture in the air condensed and formed a cloud that mirrored in appearance the symmetrical form of the volcano.

Above the peak, well separated from the principal cloud cap, is a secondary cloud of the same origin. As the current of air continued to ascend into the atmosphere, it cooled further, and more moisture condensed to form the second cloud.



WAVE CLOUDS—The illustration shows stratocumulus and altocumulus clouds, formed when wind blowing horizontally over the ocean encountered relatively high ground or mountains. As the air moved over the mountains, it followed an undulating or wavelike path, with alternately rising and falling air currents. Lenticularis (lens-shaped) clouds formed at the crests of these waves. Under wind conditions such as these, gliders can reach great heights, cover great distances, and make flights of long duration.



HURRICANE CLOUDS—When a hurricane forms over tropical seas, a crown of clouds curls up, following the typical rotation of winds around the eye of the storm. Specially equipped airplanes are used to follow the movements of these tropical cyclones.

This photograph, taken from the Gemini XII capsule, shows how a hurricane looks from a great altitude. Similar images (the color is of some importance) are also obtained by special television cameras installed aboard artificial weather satellites.

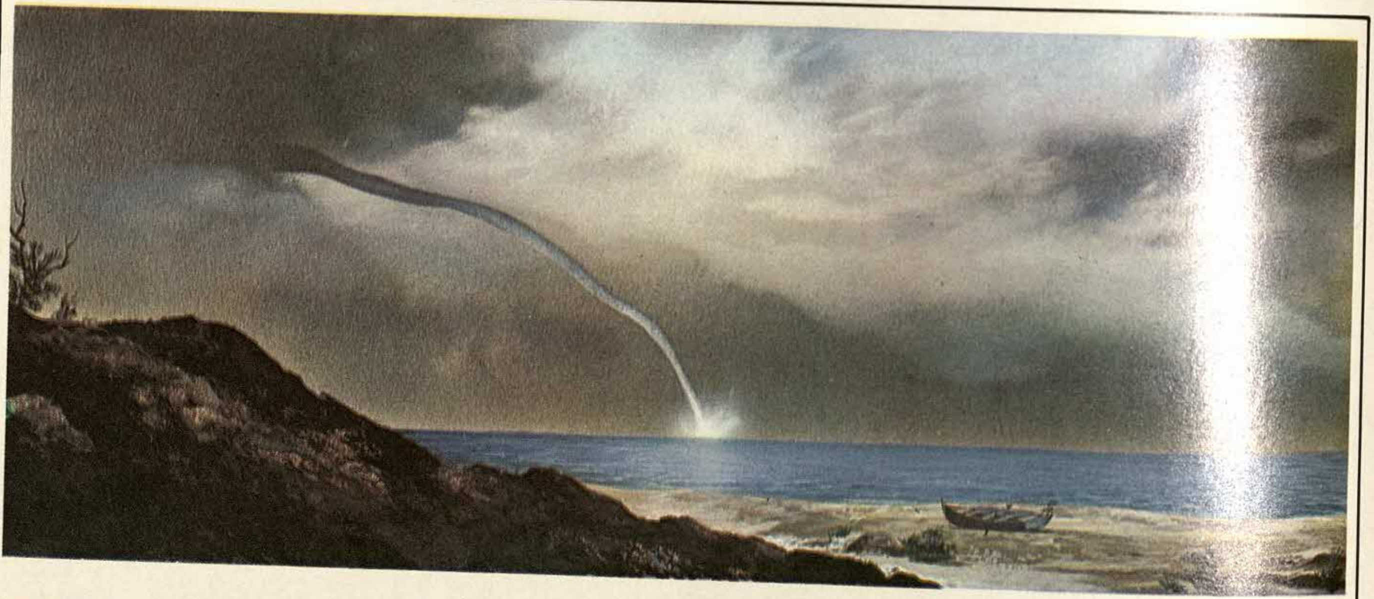
VERY RARE NOCTILUCENT CLOUDS—Somewhat resembling mother-of-pearl clouds, noctilucent clouds form at very great altitudes, ranging from 60 to 100 km (about 37 to 62 mi). They are visible for up to two hours after the sun sets when the rest of the sky is almost completely dark. Because they are formed at such great altitudes, they receive all the rays of the sun, even when the lower clouds are completely in the dark. Noctilucent clouds are sometimes colored with marvelous tints, which change with the winds and with the motion of the sun, taking on delicate tones.

Under good meteorological conditions, such as when a transparent sky is viewed from a seashore, a high mountain, or an airplane, the sight of a noctilucent cloud is quite spectacular.

A CLOUD OF PRECIPITATION—Falling from a large isolated cloud, snow may produce formations that resemble clouds. This photograph shows a large cumulonimbus formed at a very northerly latitude; a snowlike precipitation falls from the cloud but evaporates before it reaches the surface of the Earth. The white cloud formed of downward-moving particles appears to merge with the base of the cumulonimbus cloud.

Clouds are not always formed of small droplets only. Large cumulus clouds sometimes contain large water drops, which remain high in the sky because of a strong ascending air current at the center of the cloud itself.

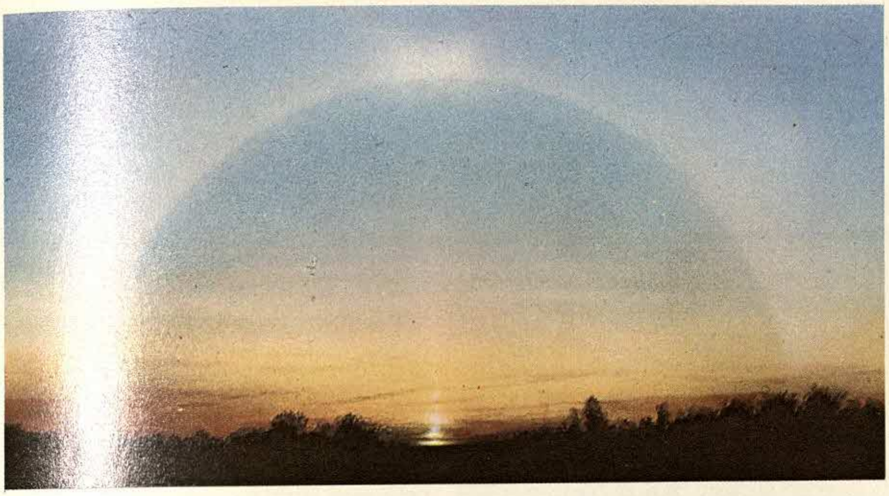
FOG—Only on the ocean can the borders of a typical fogbank be clearly observed. For example, under particular meteorological conditions on the North Atlantic, masses of hot air blow northward and are cooled. This photograph shows fog resting on the edge of the sea.



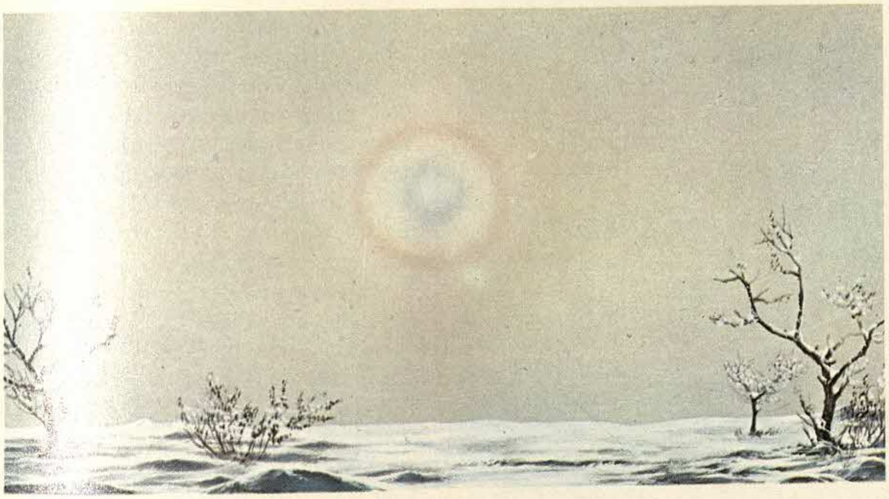
THE TORNADO—Under certain meteorological conditions—for example, when there are cumulonimbus clouds with strong ascending currents—a tornado or atmospheric whirlwind may be produced. The tornado is characterized by a funnel-shaped cloud—sometimes vertical, sometimes sloping—that may descend to the surface of the ground or the ocean. Because of centrifugal acceleration due to the rapidly whirling wind in the body of the tornado, the center of the storm has very low pressure, which causes objects containing air to burst as the tornado passes. The reciprocal friction of solid and liquid particles in the tornado produces intense electrification, so that electrical phenomena of limited range may occur. The passage of a tornado is always very destructive.

This illustration shows a waterspout, in which water is lifted up by the powerful updraft at the center of a funnel cloud.

CLOUDS OF SAND—Particularly violent blasts of wind in desert areas may pick up great quantities of sand from the ground and keep this material suspended by turbulence. The sand clouds shown in this photograph resemble a vast cumuliform cloud moving horizontally along the ground at great velocity.



THE PARHELIC CIRCLE—Under certain meteorological conditions, tiny ice prisms suspended in the air diffract the sun's rays to form a diffraction ring, or halo—the parhelic circle—around the sun. The phenomenon is shown in this photograph. A bright spot along the parhelic circle is called a parhelion or mock sun.



THE ANTHELION—The anthelion or antisun is an optical atmospheric phenomenon seen in the direction exactly opposite the sun. It is caused by the refraction of sunlight by the water droplets of a cloud.

The phenomenon is similar to that occurring when an observer is on a mountaintop, with a sea of clouds beneath the summit and the sun relatively low on the horizon. Facing in the direction opposite the sun, the observer sees his own image at the center of concentric rings that are colored from violet near the center to red on the outer edges; the image appears surrounded by a halo. For this reason, the name "gloria" is applied to the anthelion.

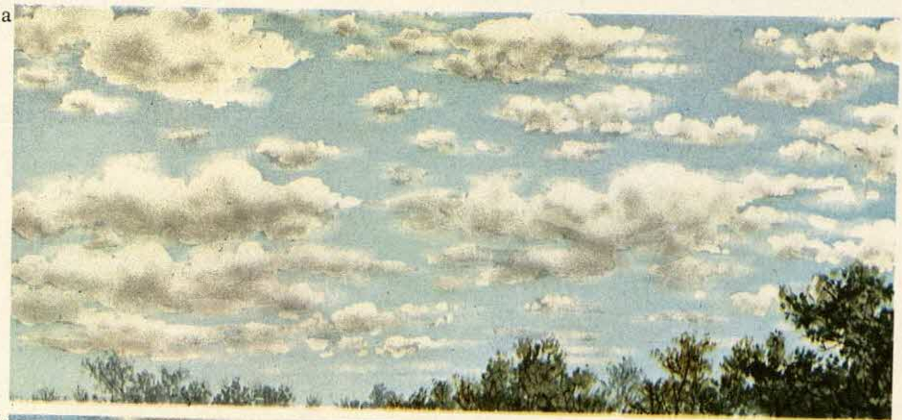
Mountain cap, nacreous, and noctilucent clouds are true clouds, composed of water droplets. Other meteorological phenomena—parhelion and anthelion—may also be attributed to clouds, because they are caused by the refraction or diffraction of light by the water droplets and the ice crystals of clouds.

Sand clouds, on the other hand, are composed of solid particles rather than water droplets. The great variety of such clouds is dependent on their natural or artificial origins, their density, the height at which they form, and so forth. Smog produced as a by-product of human activity consists of clouds of solid particles combined with liquids. Dust clouds produced by volcanic eruptions consist of very fine particles and often rise to great altitudes, even reaching into the stratosphere; such clouds may remain there long enough to make several revolutions of the Earth. Dust and sand grains blown from deserts and transported by winds across the ocean may follow a similar path. In recent years, scientists have accurately studied atmospheric circulation at high altitudes, especially in the stratosphere, by following the movements of radioactive clouds produced by nuclear explosions. The high temperatures generated by these explosions draw the dust into the stratosphere, from where it is distributed over all the Earth. Scientists have traced the path of this diffusion by taking samples of stratospheric air and by using sounding balloons.

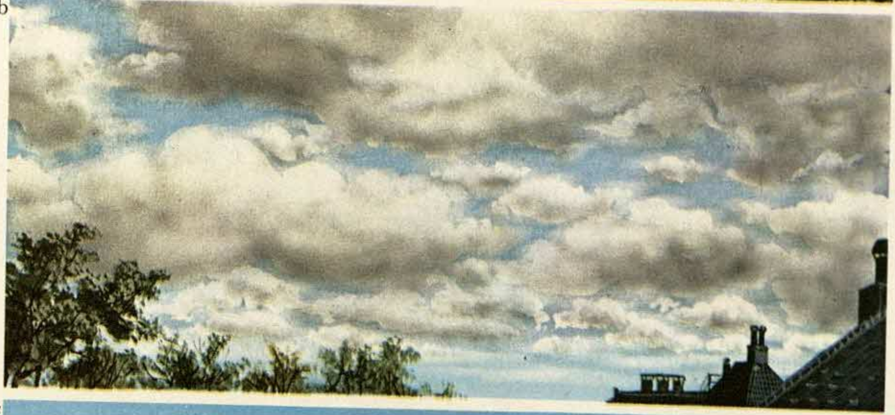
THE RAINBOW—The beautiful phenomenon known as a rainbow is produced by the refraction of sunlight by falling water droplets. Ordinarily a rainbow occurs when bright sunlight shines on precipitation from a cloud of limited horizontal extension, such as a cumulonimbus cloud. The water droplets through which the sunlight passes serve as tiny prisms to bend or refract the rays of white light, separating them according to their respective wavelengths into lights of different colors and arranging them as a set of concentric arcs. The rainbow, to an observer, appears outside the cloud-covered area and separate from the precipitation. Occasionally rainbows may appear in pairs, with one bow more intense than the other.

TROPOSPHERIC CLOUDS | everyday forms in the sky

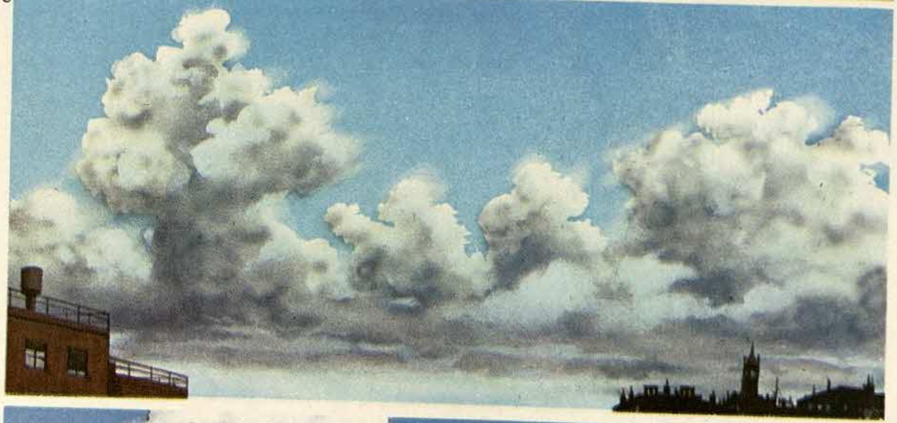
1a



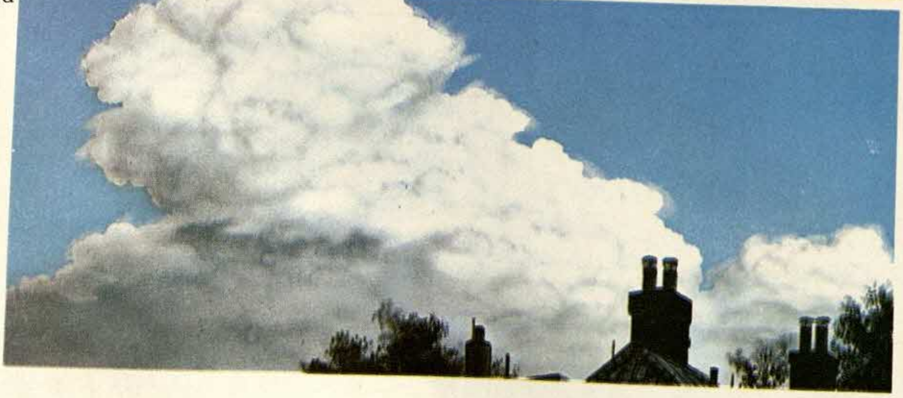
1b



1c



1d



People watch the sky for a variety of reasons. Many simply delight in the beautiful picture of billowing clouds against a background of a clear blue sky. Others find relaxation in daydreaming as they watch the clouds parade overhead. However, in addition to these esthetic and recreational reasons, many people observe the sky, looking for significant indicators of meteorological phenomena. Among the more serious sky watchers are professional weather scientists, amateur meteorologists, farmers, fishermen, airplane pilots, and sailors of vessels large and small on lakes and seas throughout the world.

As an aid to the study of atmospheric phenomena, scientists have classified clouds into genera (families), species, and varieties. Moreover, they have identified additional characteristics of certain clouds, which help to distinguish them from other clouds. Finally, they have devised standard code symbols and abbreviations that may be used on weather maps and meteorological charts to identify clouds with great precision and in thoroughgoing detail.

The clouds depicted and described on these pages are those normally formed in the troposphere or lower part of the atmosphere, where very strong vertical movements of air are generally responsible for cloud formation and precipitation.

CUMULUS FAMILY—These various types of cumulus clouds are described on the basis of their vertical development.

Cumulus humilis (Illustration 1a) has well-defined lower limits, but a modest vertical extent (hence the term *humilis*).

Cumulus mediocris (Illustration 1b) has greater vertical development than *Cumulus humilis*. The diverse clouds in the genus *Cumulus* are symbolized by numerical coefficients—a low number for thin clouds, a higher number for thicker ones. The coefficient for *humilis* is 1; for *mediocris,* 2.

Cumulus congestus (Illustration 1c) has somewhat greater vertical development than those clouds previously described. Its upper extremities form distinct rounded masses (*mammelloni*), which spread in various directions. Its lower edge is flat and dark because of its great thickness.

Cumulonimbus calvus (Illustration 1d) is the most advanced stage of cumulus development. It is a large, towering cloud, reaching into very clear atmospheric strata, often to altitudes of 6,000–8,000 m (about 19,700 ft to 26,250 ft). Under this cloud, a heavy storm is visible.

THE CLASSIFICATION OF CLOUDS

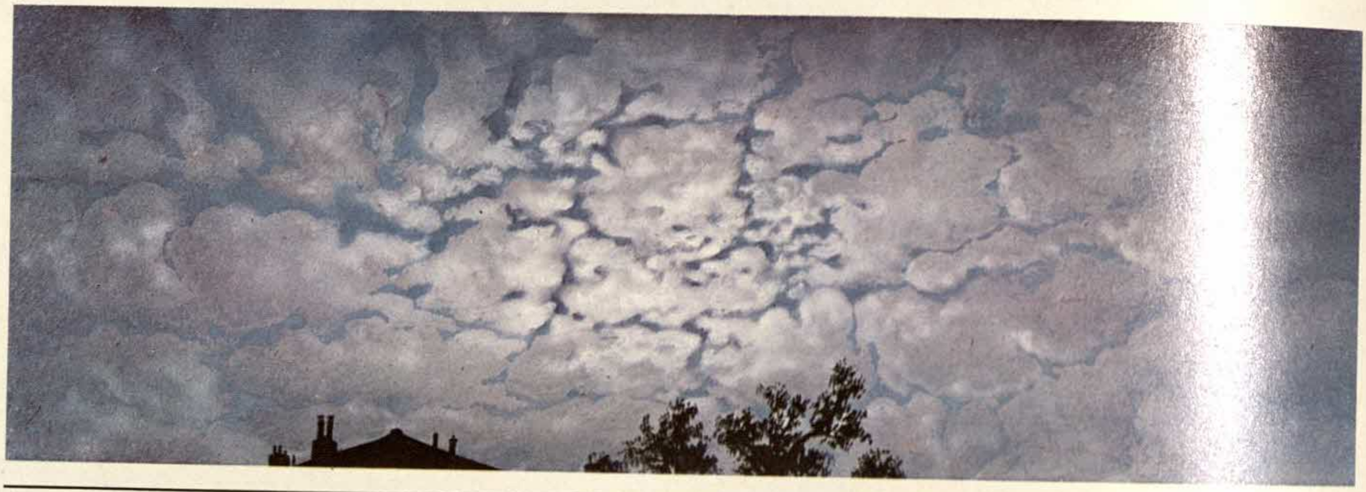
GENERA	SPECIES	VARIETIES	CHARACTERISTICS	ORIGINS AND MUTATIONS	
Cirrus [Ci]	fibratus [fib] uncinus [unc] spissatus [spi] castellanus [cas] floccus [flo]	intortus [in] radiatus [ra] vertebratus [ve] duplicatus [du]	mamma [mam]	Cirrocumulogenitus Altocumulogenitus Cumulonimbogenitus	Cirrostratomutatus
Cirrocumulus [Cc]	stratiformis [str] lenticularis [len] castellanus floccus	undulatus [un] lacunosus [la]	virga [vir] mamma	———	Cirromutatus Cirrostratomutatus Altocumulomutatus
Cirrostratus [Cs]	fibratus nebulosus [neb]	duplicatus undulatus	———	Cirrocumulogenitus Cumulonimbogenitus	Cirromutatus Cirrocumulomutatus Altostratomutatus
Altocumulus [Ac]	stratiformis lenticularis castellanus floccus	translucidus [tr] perlucidus [pe] opacus [op] duplicatus undulatus radiatus lacunosus	virga mamma	Cumulogenitus Cumulonimbogenitus	Cirrocumulomutatus Altostratomutatus Nimbostratomutatus Stratocumulomutatus
Altostratus [As]	———	translucidus opacus duplicatus undulatus radiatus	virga praecipitatio [pra] pannus [pan] mamma	Altocumulogenitus Cumulonimbogenitus	Cirrostratomutatus Nimbostratomutatus
Nimbostratus [Ns]	———	———	praecipitatio virga pannus	Cumulogenitus Cumulonimbogenitus	Altocumulomutatus Altostratomutatus Stratocumulomutatus
Stratocumulus [Sc]	stratiformis lenticularis castellanus	translucidus perlucidus opacus duplicatus undulatus radiatus lacunosus	mamma virga praecipitatio	Altostratogenitus Nimbostratogenitus Cumulogenitus Cumulonimbogenitus	Altocumulomutatus Nimbostratomutatus Stratomutatus
Stratus [St]	nebulosus fractus [fra]	opacus translucidus undulatus	praecipitatio	Nimbostratogenitus Cumulogenitus Cumulonimbogenitus	Stratocumulomutatus
Cumulus [Cu]	humilis [hum] mediocris [med] congestus [con] fractus	radiatus	pileus [pil] velum [vel] virga praecipitatio arcus [arc] pannus tuba [tub]	Altocumulogenitus Stratocumulogenitus	Stratocumulomutatus Stratomutatus
Cumulonimbus [Cb]	calvus [cal] capillatus [cap]	———	praecipitatio virga pannus incus [inc] mamma pileus velum arcus tuba	Altocumulogenitus Altostratogenitus Nimbostratogenitus Stratocumulogenitus Cumulogenitus	Cumulomutatus

CLOUD CLASSIFICATION—The table shows the classification of clouds by genera, species, and variety. The genus is an indication of the height at which a cloud appears. The species designation indicates the cloud's shape and general structure, and the variety further describes the appearance of the cloud, including its transparency and geometric characteristics. Certain supplementary characteristics of rare occurrence depend either upon the manner in which the cloud originated or on the clouds with which it is associated. For example, *Cirrus mamma* is a high-altitude cloud with hanging protuberances on the undersurface. The term *praecipitatio* indicates that rain is falling from the base of the cloud. It is important to establish the kind of cloud with which such a *praecipitatio* is associated.

Clouds are also distinguished by their origin—for example, *Cumulogenitus* or *Cumulonimbogenitus.* It is necessary to specify all characteristics of a cloud. For example, the development of a cloud as a mutation of another cloud indicates the development of particular meteorological phenomena. In the table are the code symbols or abbreviations used to represent clouds on meteorological charts.

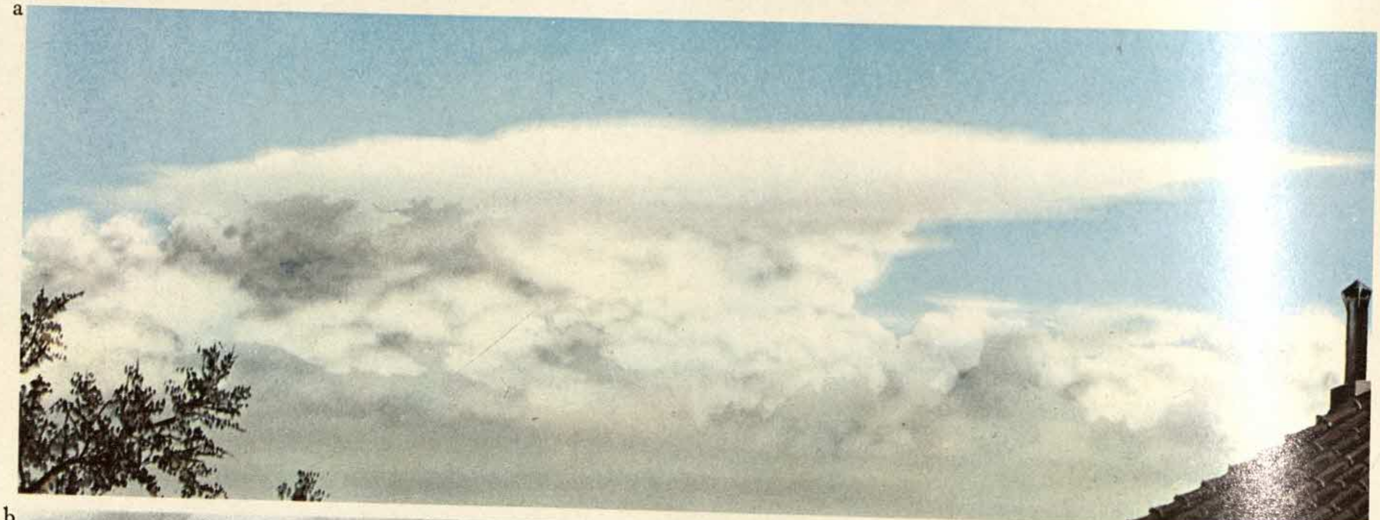
AN INTERMEDIATE TYPE—This photograph shows typical stratocumulus clouds, which are intermediate between those with horizontal extension, such as stratus, and those with vertical extension, such as cumulus. Stratocumulus clouds form a very flattened layer and develop only at heights over 1,500 m (about 4,920 ft), the lower limit for *cumulus* in the temperate zone.

3



4

a



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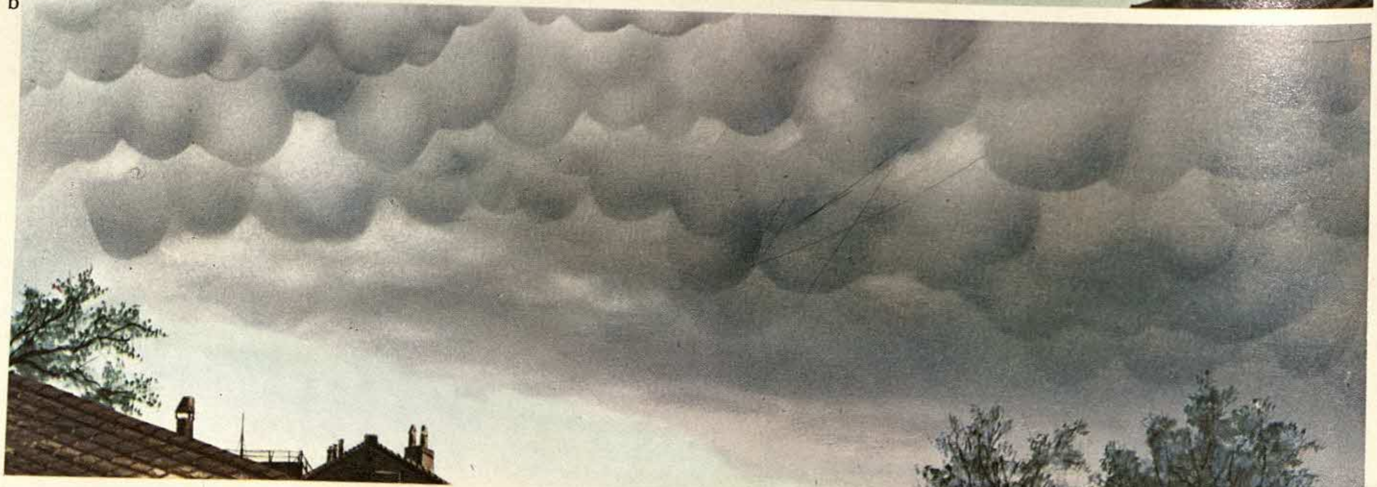
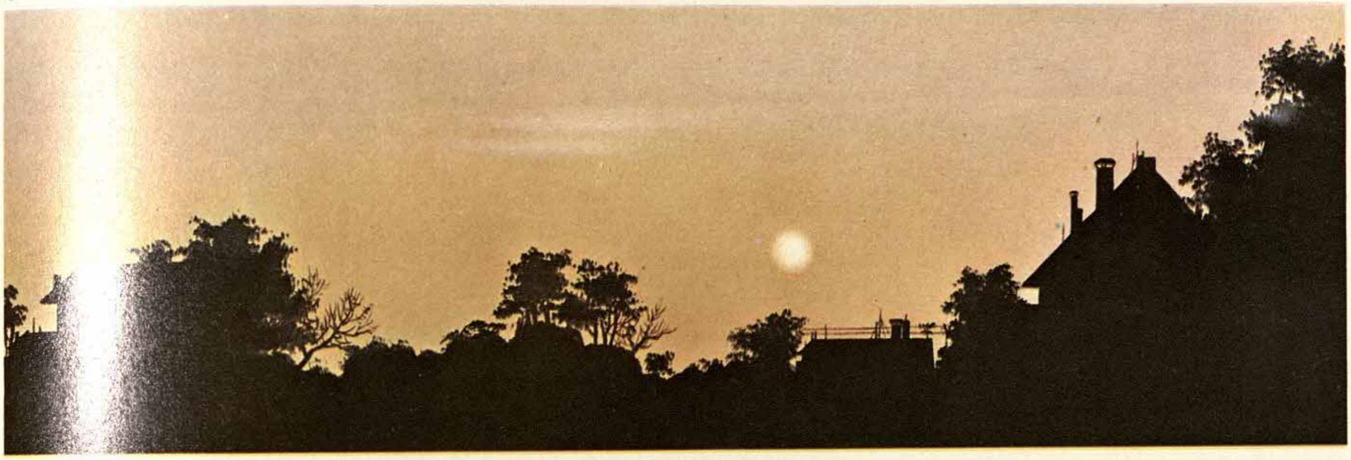


SPECIES AND CHARACTERISTICS OF CUMULONIMBUS—*Cumulonimbus capillatus incus* (Illustration 4a) is a typical thunderhead cloud. It differs from *Cumulonimbus calvus* in that its upper edge is bordered by a horizontally spreading stratiform cloud, either a stratocumulus or a cirrus. The one shown, though not well defined, is more likely of the cirrus type. Clouds of this type attain exceptional heights, up to 10–12 km (about 6 to 7.5 mi); their vertical development is even greater at tropical latitudes. Under particularly adverse meteorological conditions, a large cumulonimbus may develop hanging breastlike protuberances on the underside of the cloud (Illustration 4b); such a cloud is described by the adjective *mamma*.

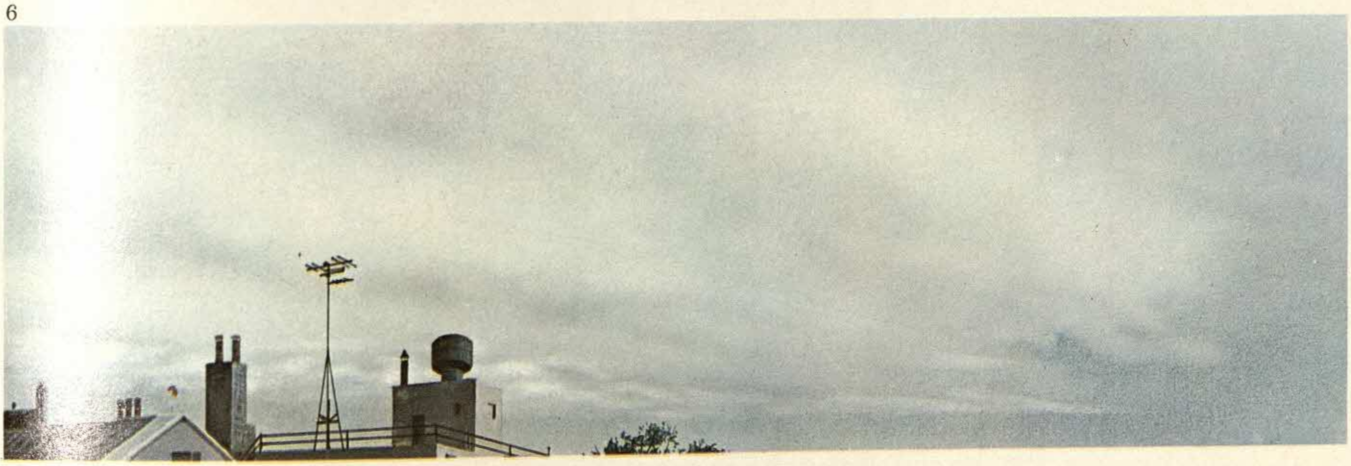
TYPICAL STRATIFORM CLOUDS—*Stratus nebulosus translucidus* is a cloud found at rather great heights; in general it forms at altitudes over 3,000 m (about 9,840 ft). This type of cloud typically extends from horizon to horizon and is very thin and transparent. The stars and the sun appear as though seen through a lamina of mother-of-pearl—hence the adjectives *nebulosus* and *translucidus.*

5



ALTOSTRATUS—*Altrostratus opacus radiatus* is an opaque stratiform cloud that may be relatively dense, but produces no precipitation. The term *radiatus* is used to indicate that the laminae are arranged in parallel bands.

6



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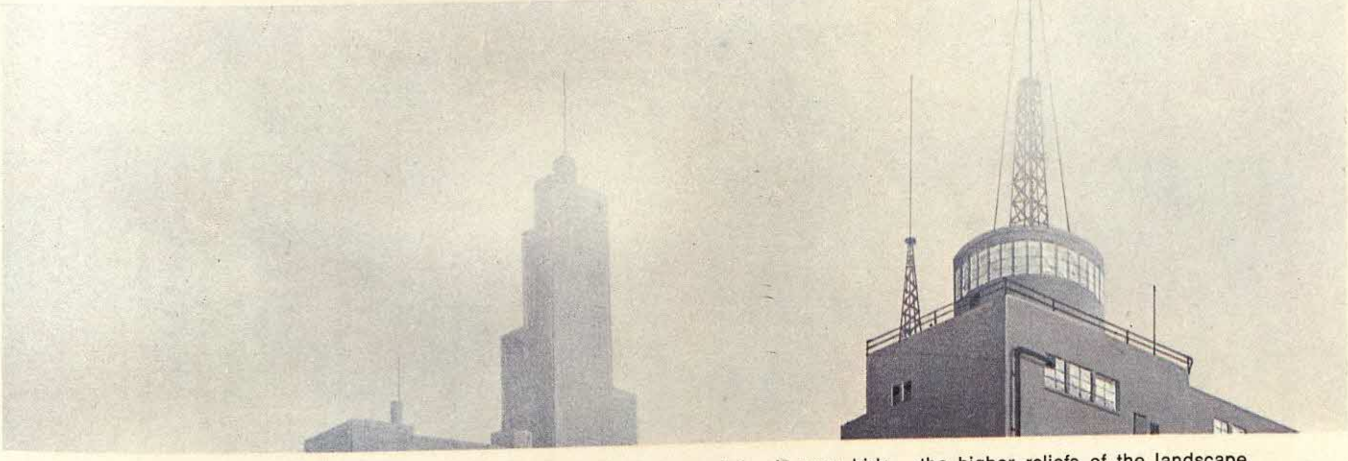


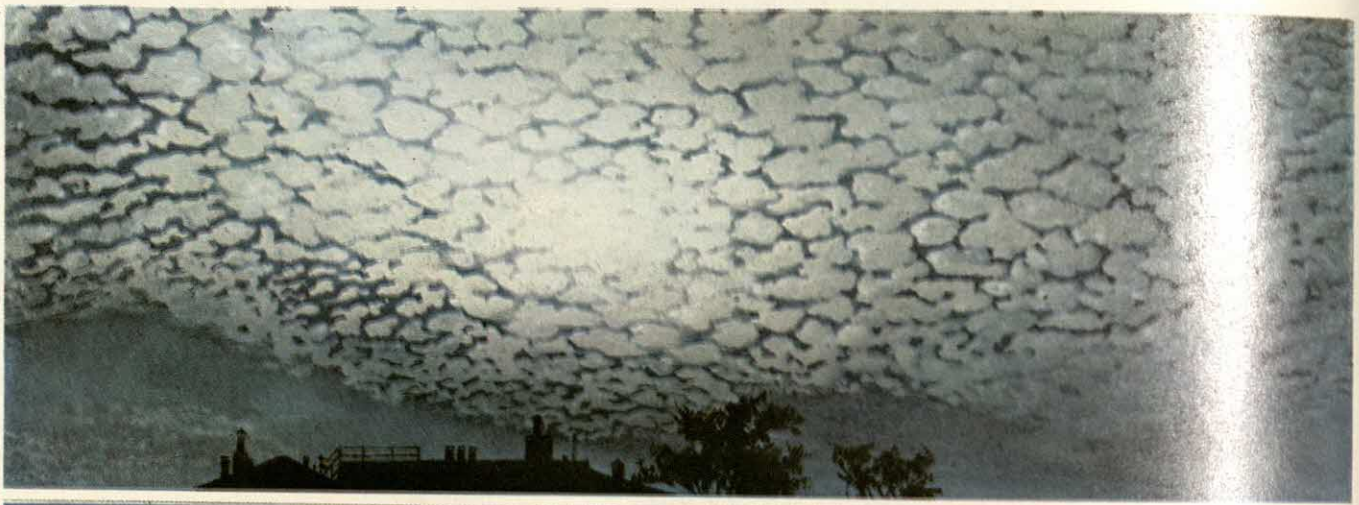
VERY LOW CLOUDS—Nimbostratus is a cloud that characteristically hugs the ground when the temperature drops rapidly. It may hide from view the upper parts of tall buildings and the higher reliefs of the landscape.

8

CLOUDS AT INTERMEDIATE HEIGHTS—Altocumulus (Illustration 8a) is typically formed of many tiny rounded masses or patches having little vertical extension (the thickness coefficient is 0) and located close to one another.

Altocumulus lenticularis (Illustration 8b) consists of patches of regular lentil-shaped clouds that ride the horizontal air currents present at relatively great heights. They are also called whale's back clouds, because they resemble the hump of a whale emerging just above the surface of the water.

a



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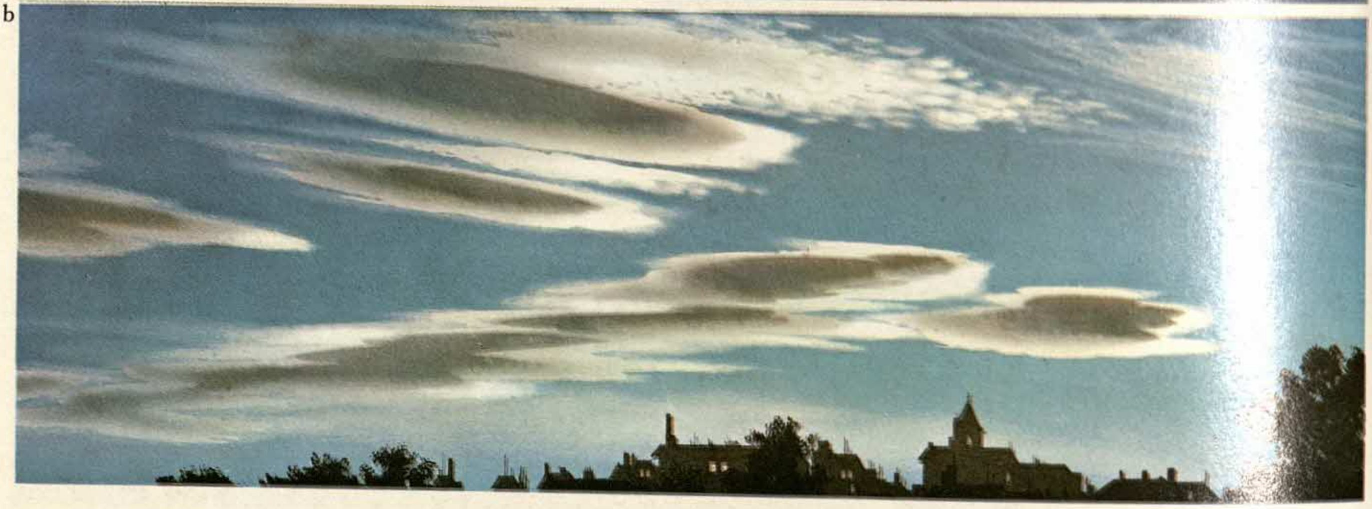

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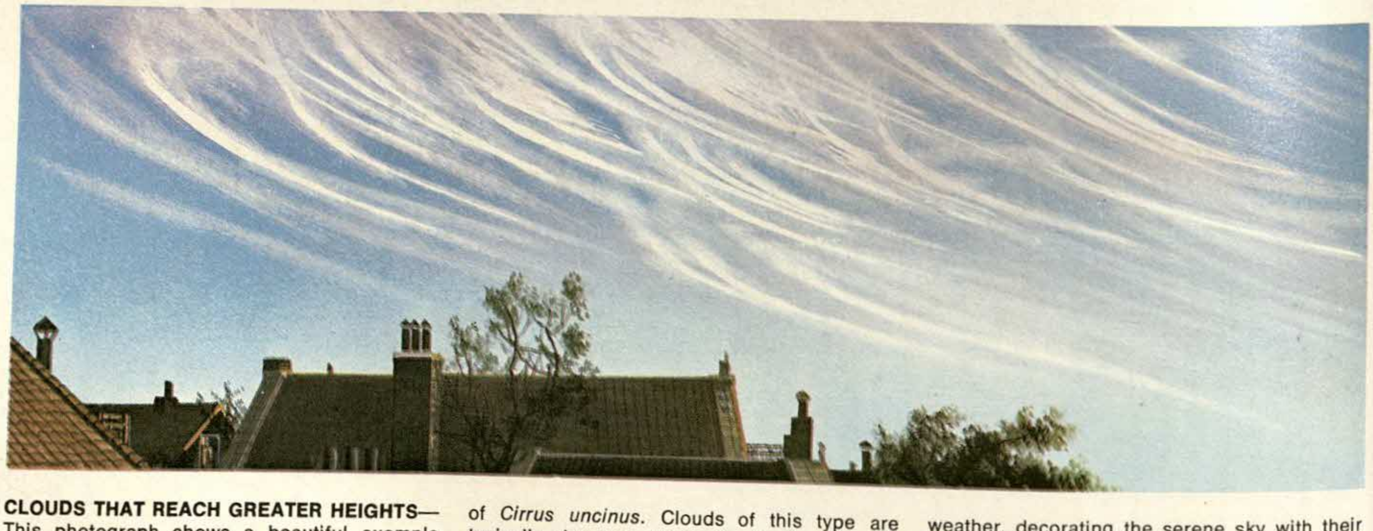


CLOUDS THAT REACH GREATER HEIGHTS—This photograph shows a beautiful example of *Cirrus uncinus*. Clouds of this type are typically observed during the daytime in good weather, decorating the serene sky with their splendid forms in both winter and summer.

WINDS AND PRESSURE SYSTEMS

the wind and its laws

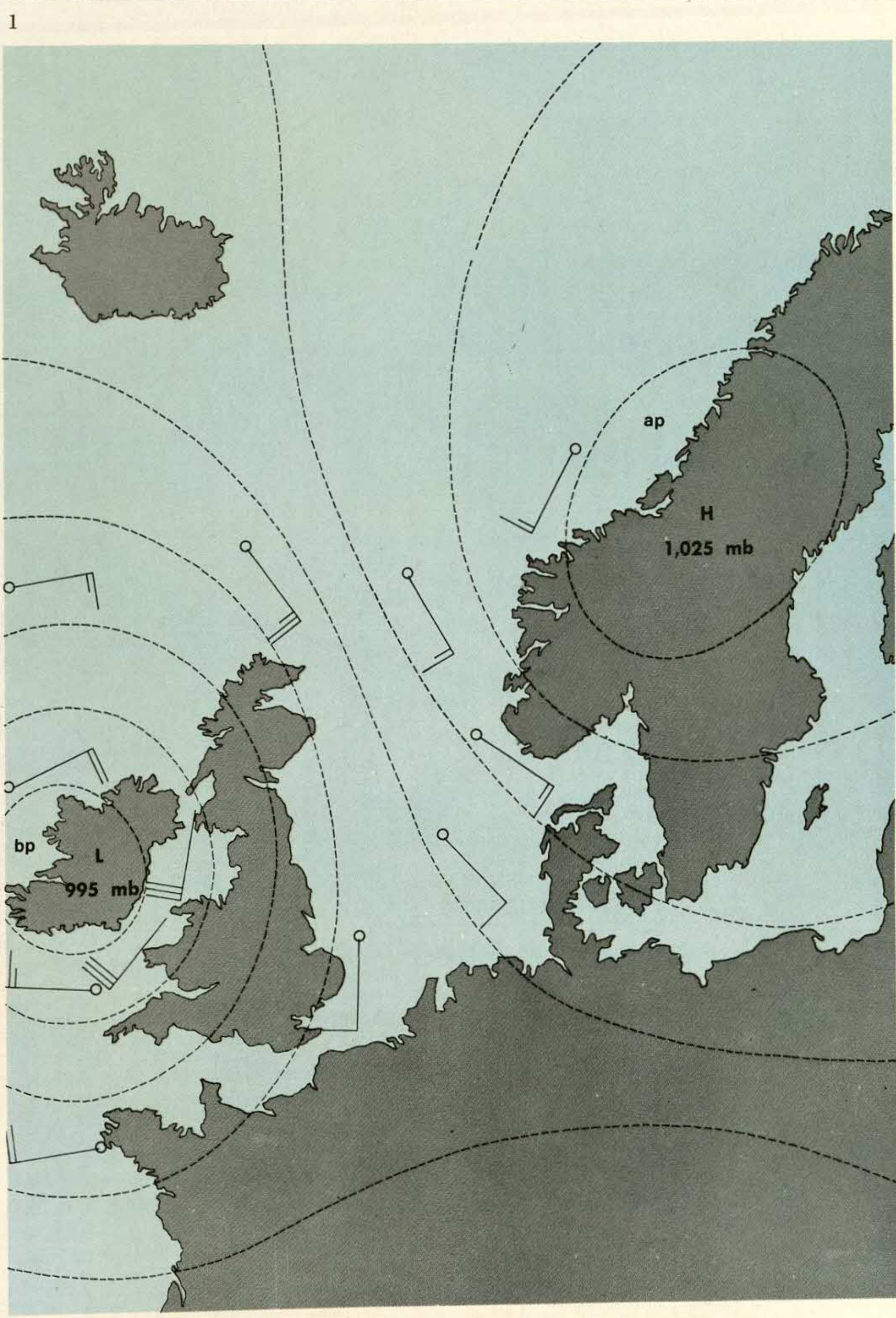
To understand changes in the weather, it is essential to know the activity of the wind—and to know how to interpret this activity by means of maps and charts. Often, a simple outline map showing pressure and temperature measurements at ground level is sufficient for determination of the course of meteorological conditions over an area; from such a map weather changes can be forecast several hours in advance. Supplementary data assure greater reliability of predictions. Most useful are systems of measurement utilizing isobars and isotherms.

Elementary data, such as wind velocity and direction, can readily be deduced from the study of barometric charts (charts showing the distribution of pressure).

BAROMETRIC CHARTS

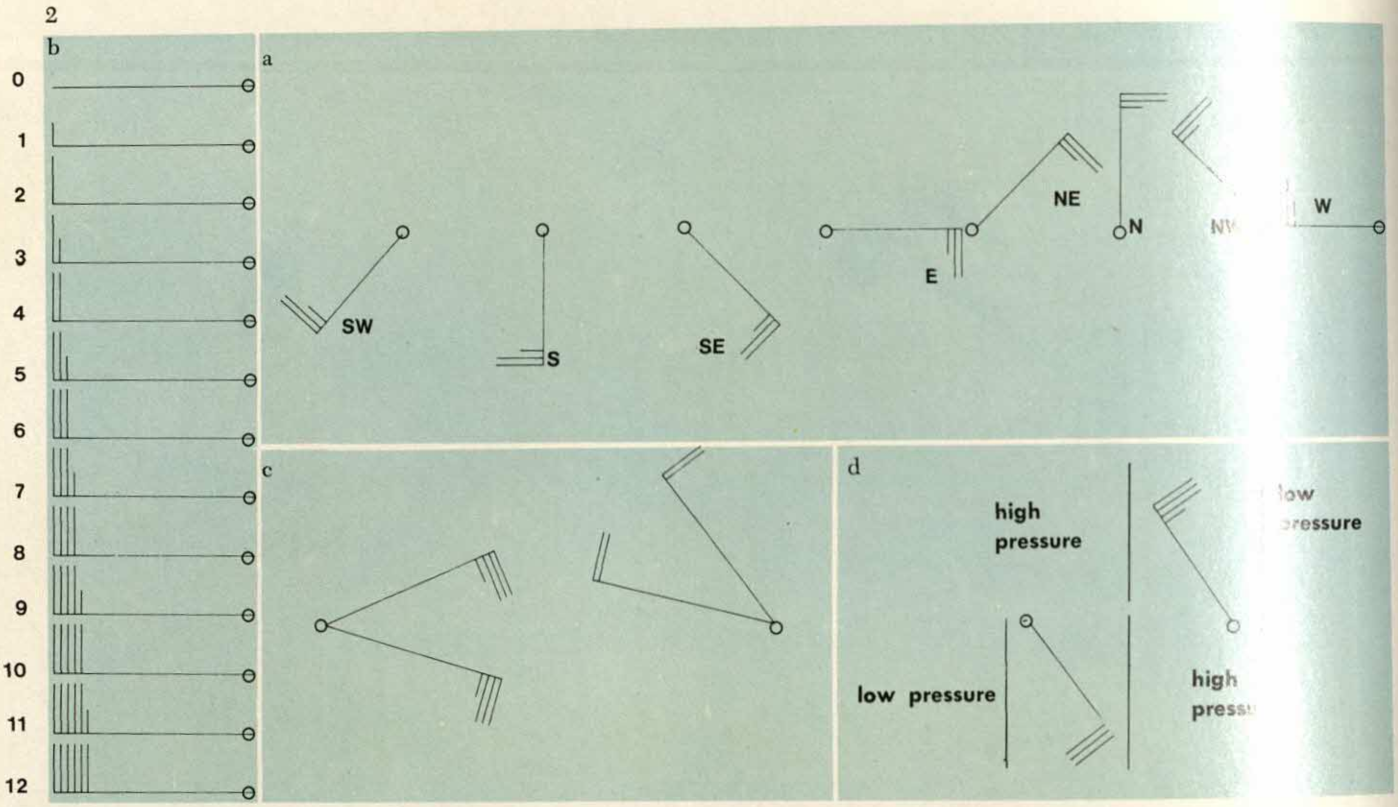
Measurements of pressure at ground level form the basis of a barometric chart. This information is normally interpolated by an electronic computer, but it is also possible to make up a chart by noting the distributions of the observation stations and the readings from each one—just as it was done before computers took over the job with speed and efficiency.

Because the mercury barometer is the most precise device for measuring air pressure, the most convenient unit of measurement is one millimeter of mer-



THE BAROMETRIC CHART—On this barometric chart of a section of western Europe, coastlines are precisely outlined; additional useful information might include locations of major cities, rivers, and land relief. Other particulars, such as valleys in the mountain ranges, can be added, but are generally superfluous. Color variations are sometimes used to emphasize the meteorological descriptions.

In this chart, isobars are shown at intervals of 4 mb. Over the British Isles is a low pressure of 995 mb; around this low front the isobars form circles. To the right, the isobars widen, but contract once again into circles around a point on the Scandinavian peninsula where a high pressure of 1,025 mb is located. Generally, the isobars are well separated.



THE SYMBOLS FOR WIND—On meteorological charts, symbols representing the wind are of considerable importance. They indicate its point of origin, the direction in which it blows, and its intensity. All these characteristics are shown by special arrows (Illustration 2a). An arrow representing the wind consists of a small circle, indicating the point where the reading of the wind intensity was made; a line (always the same length, regardless of wind direction and intensity) indicating the direction in which the wind is blowing; and "feathers" representing the intensity.

The arrows shown in Illustration 2b represent the intensity of the wind according to the Beaufort scale (Illustration 4) and have values from 0 to 12. Each short feather represents one unit of the scale; a long feather represents two units.

On charts, it is often necessary to show the tendency of the wind to change quadrant—that is, the direction from which it blows. Arrows turning clockwise (Illustration 2c) indicate that the wind is advancing through the points of the compass. Wind that is shifting in the opposite direction is said to be retreating.

In the Northern Hemisphere, arrows are drawn with the feathers on the side of the isobars of the lowest pressure; in the Southern Hemisphere, they are drawn the opposite way (Illustration 2d).

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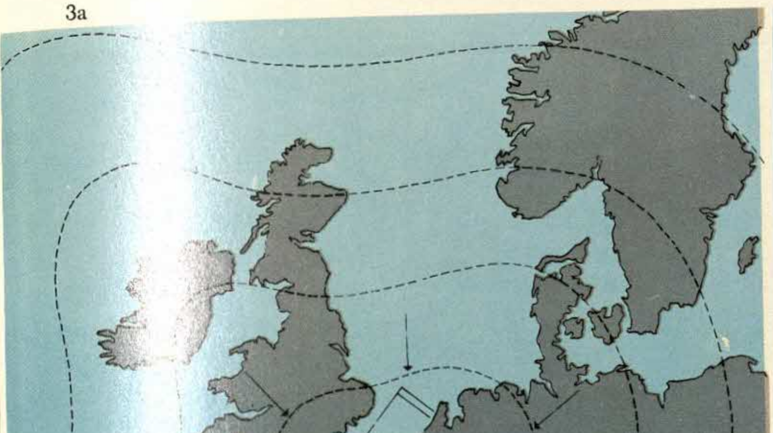
cury. To the physicist, however, this is a hybrid unit, far removed from the CGS (centimeter-gram-second) system. Therefore, it is preferable to use a unit known as a bar, which corresponds to a pressure of 1,000,000 dynes/cm^2. A bar corresponds to 0.98629 atmospheres; an atmosphere is equivalent to 1.0133 bars. The millibar (mb)—1/1,000 of a bar—is the unit of measurement used on barometric charts.

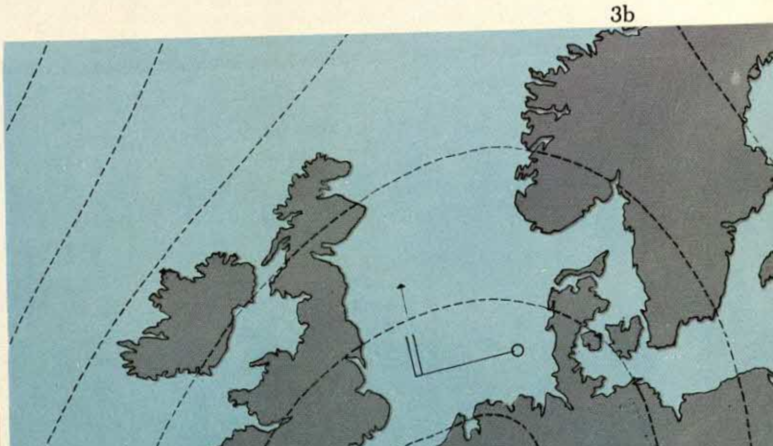
Very precise instruments can give readings of atmospheric pressure variation to within 1/10 mb. Isobars are traced on the charts at intervals of 4 mb. A reading aloft is usually obtained from an aneroid barometer or, occasionally, a hypsometer. At heights over 50 km (about 30 mi), more sensitive devices are used.

From a barometric chart, the characteristics of wind generated as a consequence of the barometric field may be deduced. For example, if high pressure exists in one region and low pressure in an adjacent region, the wind tends to blow from the first region to the second. Actually, the situation is complicated by other factors that also determine the course of the wind. Still, the study of air pressure patterns is basic to any knowledge of wind activity; other meteorological phenomena, too, are affected by high and low pressures.

3a



3b



BAR GRADIENT AND CIRCULATION—A bar gradient is a measurement of the density of isobars per unit of length on a meteorological chart. It can also be defined as the variation of pressure per unit of horizontal distance at ground level. An intense or strong bar gradient signifies a considerable difference of pressure between nearby points; a weak bar gradient means only a slight difference of pressure. Where the bar gradient is strong, the wind blows hard; where it is weak, the wind is gentle because of the lesser force exerted by the pressure of the air mass.

Thermal effects also exert some control over the motion of air masses. For example, winds may be stronger during the hot hours of the day than at night. The seacoast and differences in terrain are other factors that can modify the direction of the wind.

The wind does not blow perpendicularly to the line of the isobar, but rather cuts the isobar at an angle. The degree of the angle is of some importance. An example follows:

Illustration 3a is a map of a low-pressure area. It might seem that the wind should blow toward the center of the isobars, in the direction indicated by the pointed arrows—that is, exactly in the direction of the gradient. Instead, however, the direction of the wind is circular, as indicated by the wind arrows. The air moves toward the center of the low-pressure area, but cuts the isobars at a very slight angle. The arrows form a spiral pointing toward the center, indicating the real movement of the wind.

The opposite situation is shown in the map in Illustration 3b, with the arrows going away from the high-pressure center area. Here, too, the arrows form segments of spirals rather than radii. Generally, in the Northern Hemisphere, circulation around a low-pressure center is counterclockwise; around a high-pressure center it is clockwise. In the Southern Hemisphere, the situation is reversed. Low- and high-pressure systems as shown in the maps are also called cyclonic areas (low pressure) and anticyclonic areas (high pressure).

THE BEAUFORT SCALE—An anemometer measures the velocity of the wind in meters per second, or nautical miles per hour (knots), or kilometers or miles per hour. However, for many purposes (particularly nautical), the "force" of the wind is preferred to the velocity. Force is based on an international scale (the Beaufort scale) that indicates the velocity by a number.

This scale is useful for correlating the force of the wind with the force of the sea, but certain reservations must be observed. When wind suddenly rises after a calm, some time passes before the waves rise to a force proportional to that of the wind. Too, in inland seas, lakes, and gulfs, wave height is less than in open seas or the oceans. Furthermore, in the ocean, the waves are long; in the inland waters, they are proportionately shorter in addition to being lower—and therefore, are more rapid. When the wind dies down, the waves decrease much more gradually in inland waters.

The illustrations show wave heights raised by various forces of wind according to the Beaufort scale.

0—Calm: the sea is mirror-like; the wind rises vertically. There are absolutely no waves. Wind velocity is less than 40 cm/sec (about 1 mph).

1—Light air: smoke deflects slightly, and the surface of the sea appears rippled by small waves that do not rise above 7 cm (about 3 in.). Wind velocity is between 40 cm/sec and 1.5 m/sec (about 1 to 3 mph), the speed at which a man normally walks.

2—Light breeze: air movement can be felt on the face; waves on the sea are between 15 and 20 cm (about 6 to 8 in.) high, and the water has a crystalline appearance. Wind velocity is between 1.6 and 3.3 m/sec (about 3 to 7 mph).

3—Gentle breeze: waves are about 60 cm (about 2 ft) high, and some billows have white crests; flags unfurl. Wind velocity is 3.4 to 5.4 m/sec (about 7 to 12 mph).

4—Moderate breeze: on the ground, the wind picks up pieces of paper; at sea, waves lengthen and become higher—to 1 m (about 3 ft)—and display white crests. Velocity is between 5.5 and 7.9 m/sec (about 12 to 18 mph).

5—Fresh breeze: sea waves rise to 1.8 m (about 6 ft), with spume blown off the crests or the crests themselves blown off; inland waters ripple. Wind velocity is between 8 and 10.7 m/sec (about 18 to 24 mph).

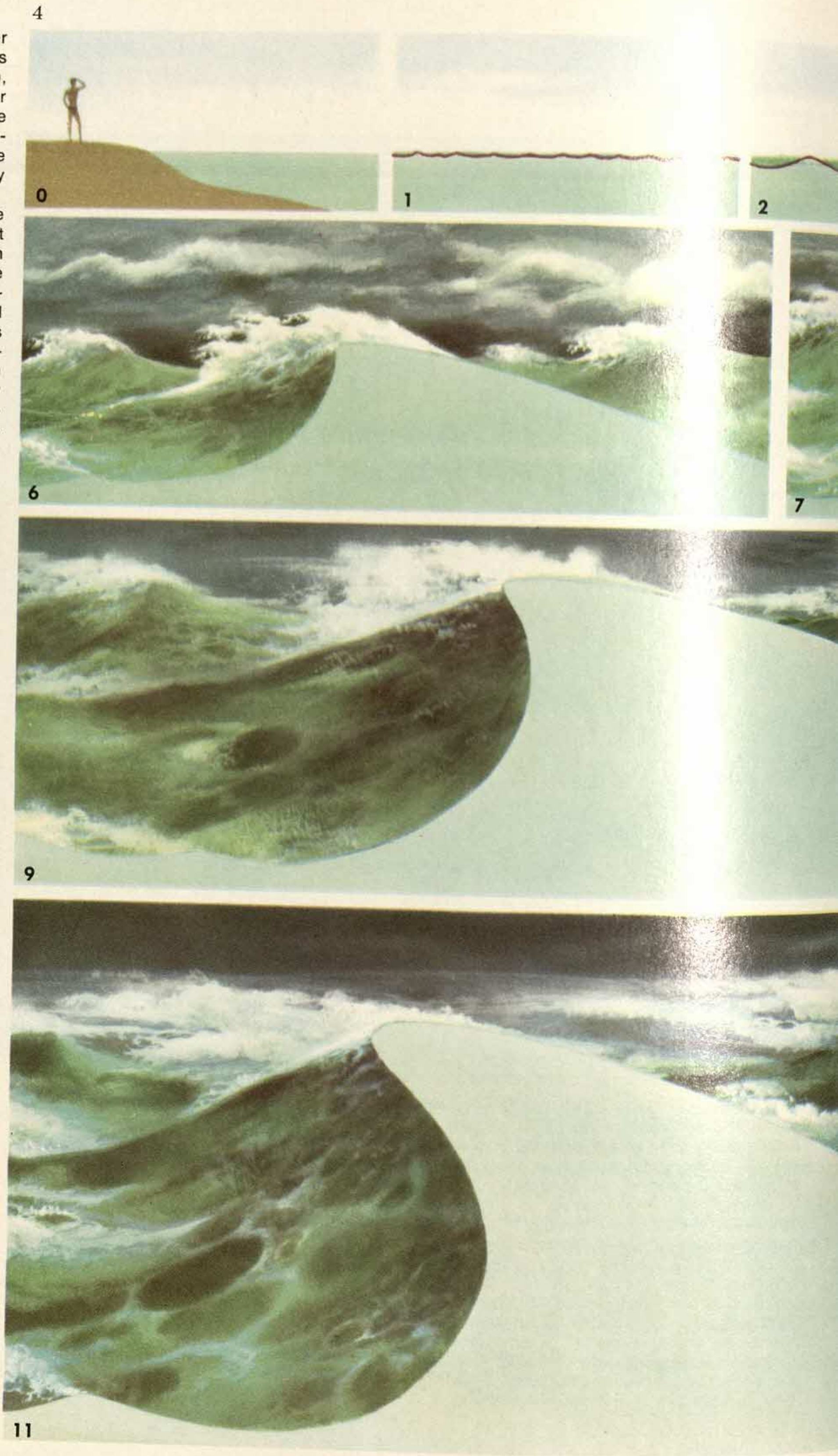
6—Strong breeze: waves up to 4 m (about 13 ft) break at the crests; spray is blown up from the surface and crest of waves; on land, tight wires whistle. Wind velocity is between 10.8 and 13.8 m/sec (about 24 to 31 mph).

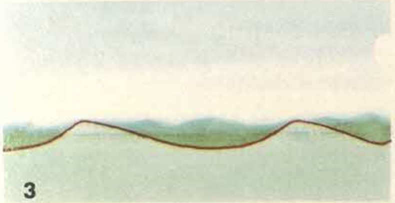
7—Moderate gale: on land such a wind is difficult to walk against, and one is pushed along when walking with it; at sea, waves reach a height of 5.5 m (about 18 ft) and streams of white spray are blown from the crests and carried by the wind. Wind velocity is 13.9 to 17.1 m/sec (about 31 to 38 mph).

8—Fresh gale: walking is impeded; waves up to 7 m (about 23 ft) high lose long filaments of spray from their crests; small boats, risking damage to their superstructures, seek shelter in ports. Wind velocity is between 17.2 and 20.7 m/sec (about 38 to 46 mph).

9—Strong gale: buildings are damaged, chimneys fall, roofing blows off; waves are more than 7 m (about 23 ft); velocity is between 20.8 and 24.4 m/sec (about 46 to 55 mph).

10—Whole gale: trees may be blown down; violent waves reach a height of 9 m (about 30 ft) and the sea's surface is covered with white spray, causing some loss of visibility. Wind is between 24.5 and 28.4 m/sec (about 55 and 63 mph).





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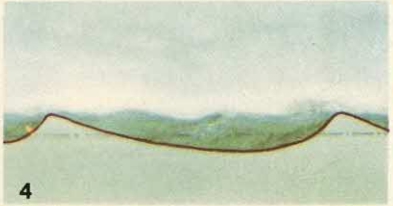

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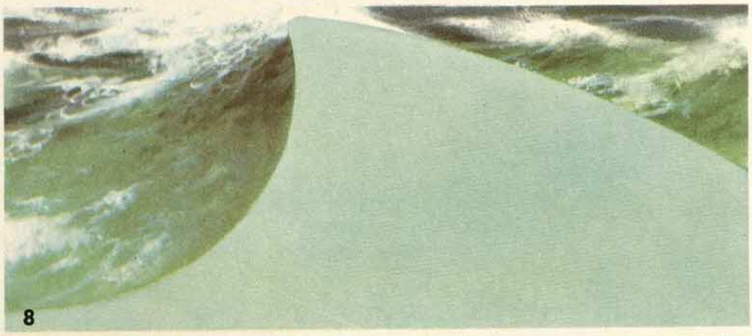

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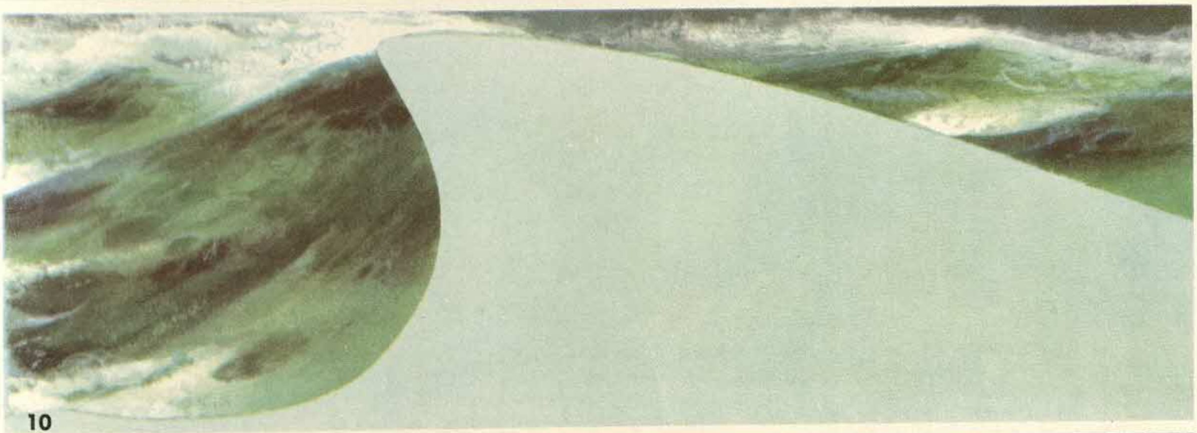

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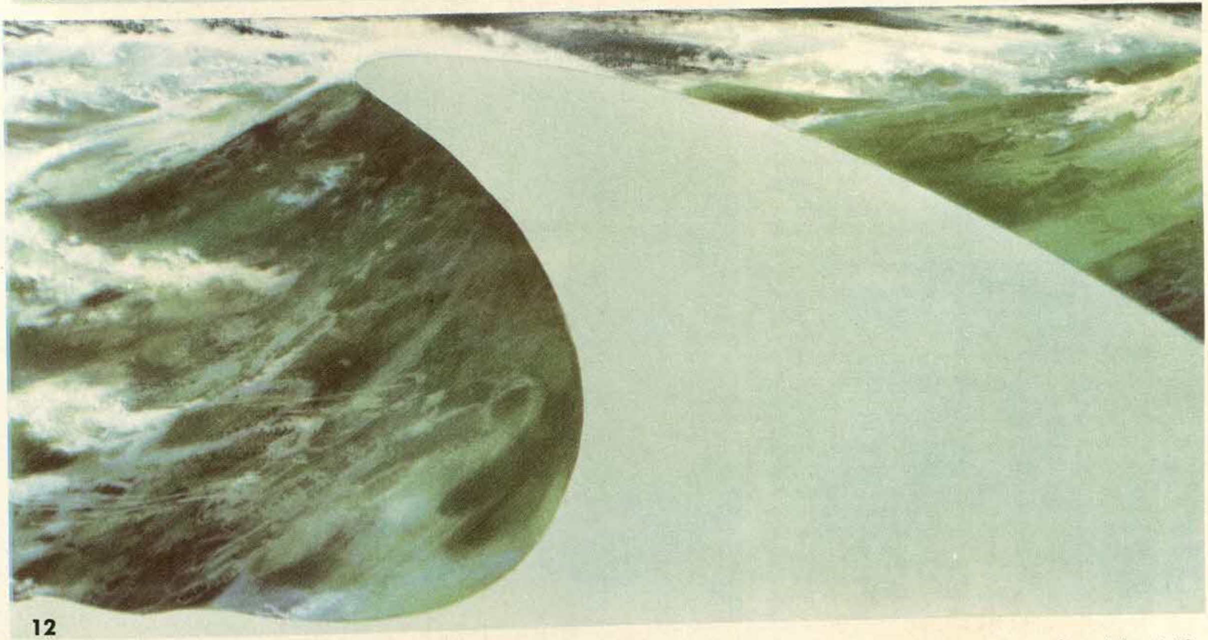

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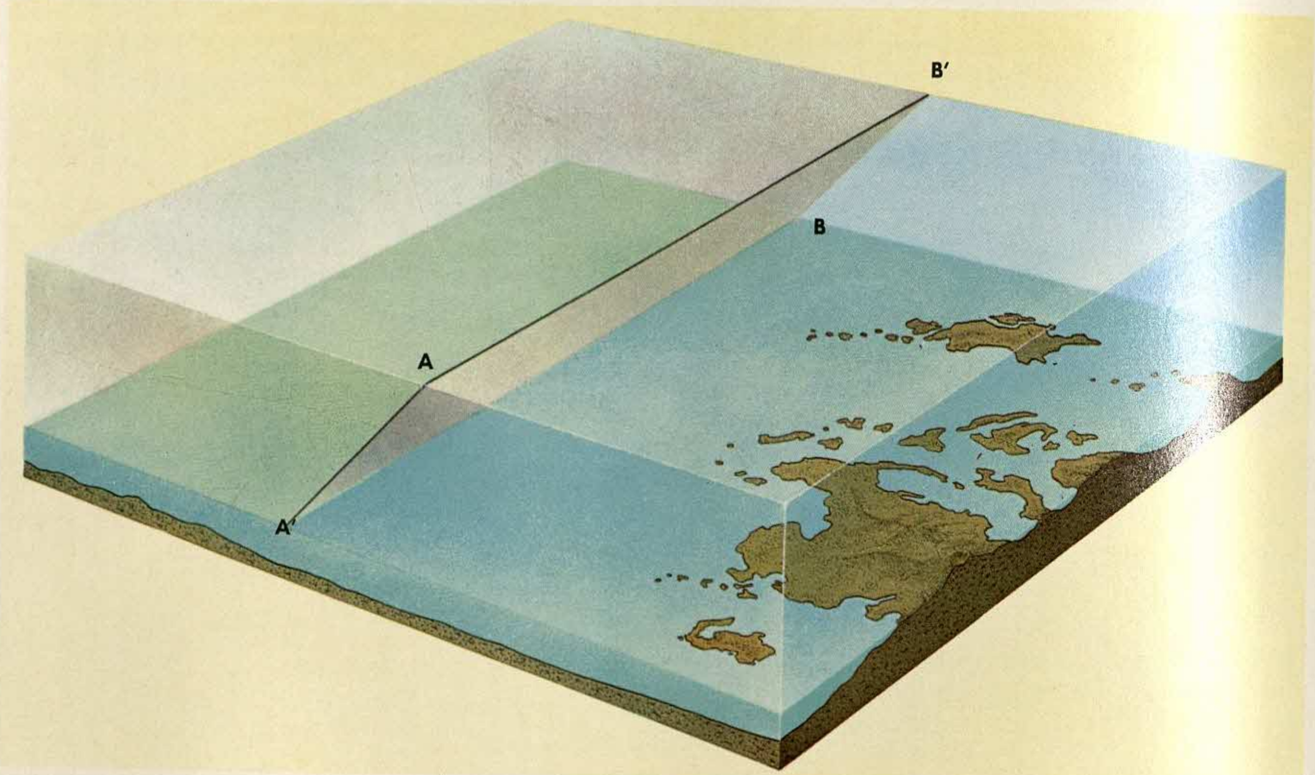
11—Storm: serious damage occurs on land and to superstructures of ships; rolling waves, covered entirely by spray, reach 11 m (about 36 ft); visibility is almost zero. Wind velocity is between 28.5 and 33.5 m/sec (about 63 and 75 mph).

12—Hurricane: on land, weaker structures are destroyed; at sea, visibility is practically zero; rolling waves are more than 13 m (about 43 ft) high; sailing boats are dismasted, ships' superstructures are damaged. Wind velocity is greater than 33.5 m/sec (75 mph).

AIR MASSES | prime factors in weather forecasting

1

a

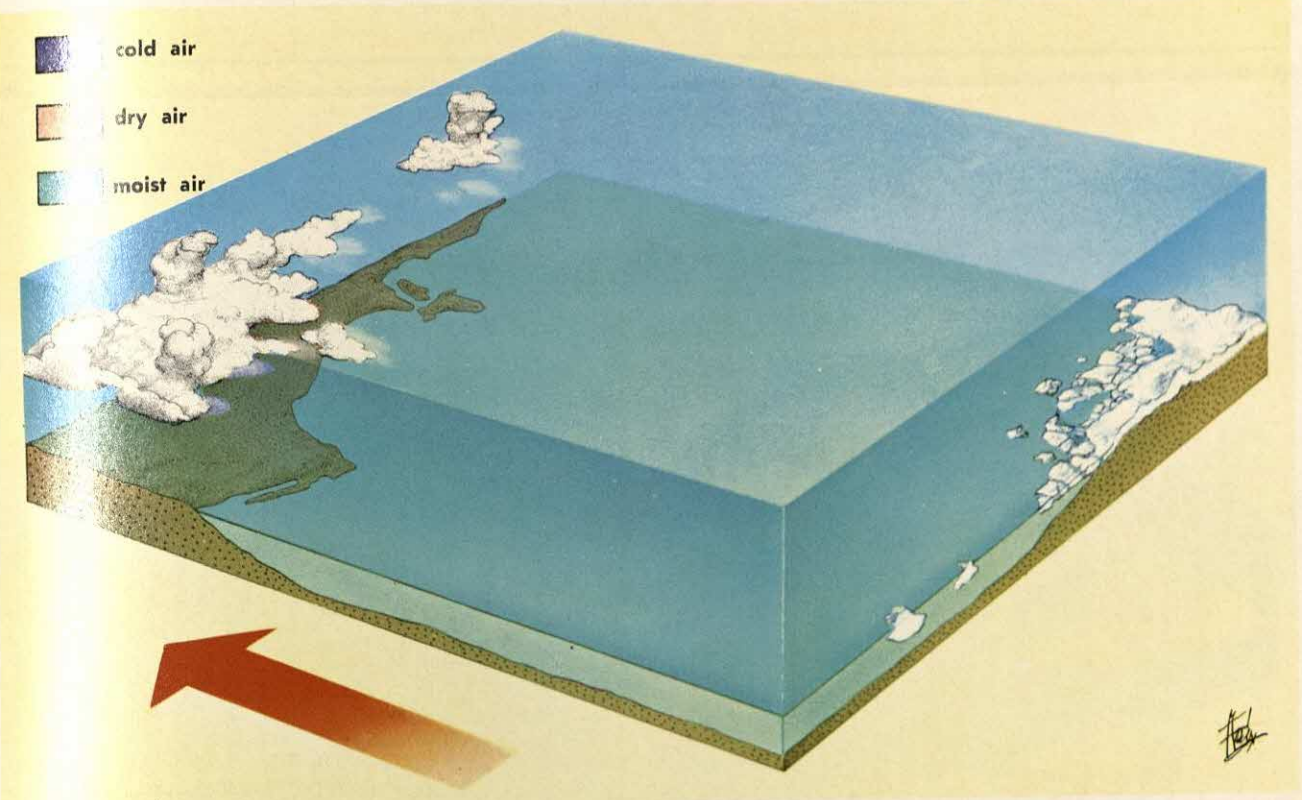


b

AIR MASSES—Illustration 1a represents two air masses meeting above a surface that is partly land and partly sea. An air mass normally has a horizontal extension of about 1,000 km (about 620 mi), with a vertical expanse. The illustration ranging from about 4 km (about 2.5 mi) to less than 10 km (about 6 mi) is exaggerated vertically for visual purposes.

The air mass on the left is warm, while that on the right is cold. The two masses come in contact along the slope **ABA′B′** of the frontal transition zone; the line corresponding to the intersection of the zone with the ground is called a front. Most phenomena of meteorological interest concern the characteristics of air masses, hot or cold, over particular regions; frontal activity is the phenomenon that occurs along the frontal zones. When two air masses approach one another, the warmer mass is forced over the cooler one, forming a front as shown in the illustration. This phenomenon produces cooling and moisture condensation with the formation of clouds and precipitation. Illustration 1b, a photograph taken from a Gemini capsule, shows such a cloud formation.

2



COLD AIR MASSES—Air masses form when air remains for a certain length of time in one region without being moved by pressure gradients. An air mass takes on the characteristics of its source region. If it remains for a long time over polar regions, it becomes cold; if it remains some time over a tropical desert, it becomes hot and relatively dry; if it remains over a tropical sea, it becomes hot and moist. Other factors governing the nature of an air mass include the season when it forms and the length of time it remains over a given area.

When air masses are set in motion, because of the establishment of a horizontal pressure gradient, they converge with other masses and bring about changes in the weather. Such changes are predictable from the characteristics of the different air masses.

An air mass coming from a polar region has a temperature lower than that of any other air mass with which it comes into contact. At the upper limits of the troposphere all air masses are very cold—approximately −50° C (−58° F). Therefore, the temperatures of polar air masses change only slightly at greater altitudes. If the temperature at the ground is −20° C (−4° F), the total gradient for the entire height of the mass is 30° C (86° F).

The lower layer of a cold air mass may be colder than the rest of the mass, because, being in contact with the ground, this layer cools rapidly. It may also have a low absolute moisture content because cold air contains less water vapor than hot air.

When cold air moves away from its source region, it gradually becomes warmer. The increase in temperature is caused partly by the greater intensity of sunlight at lower latitudes, but chiefly by its contact with warmer ground. Therefore, the lower part of the air mass becomes warmer, and it becomes unstable in that it tends to rise, forming cumulus clouds. As the air warms up, it is able to absorb moisture and to produce precipitation. During the heating phase the air remains clear.

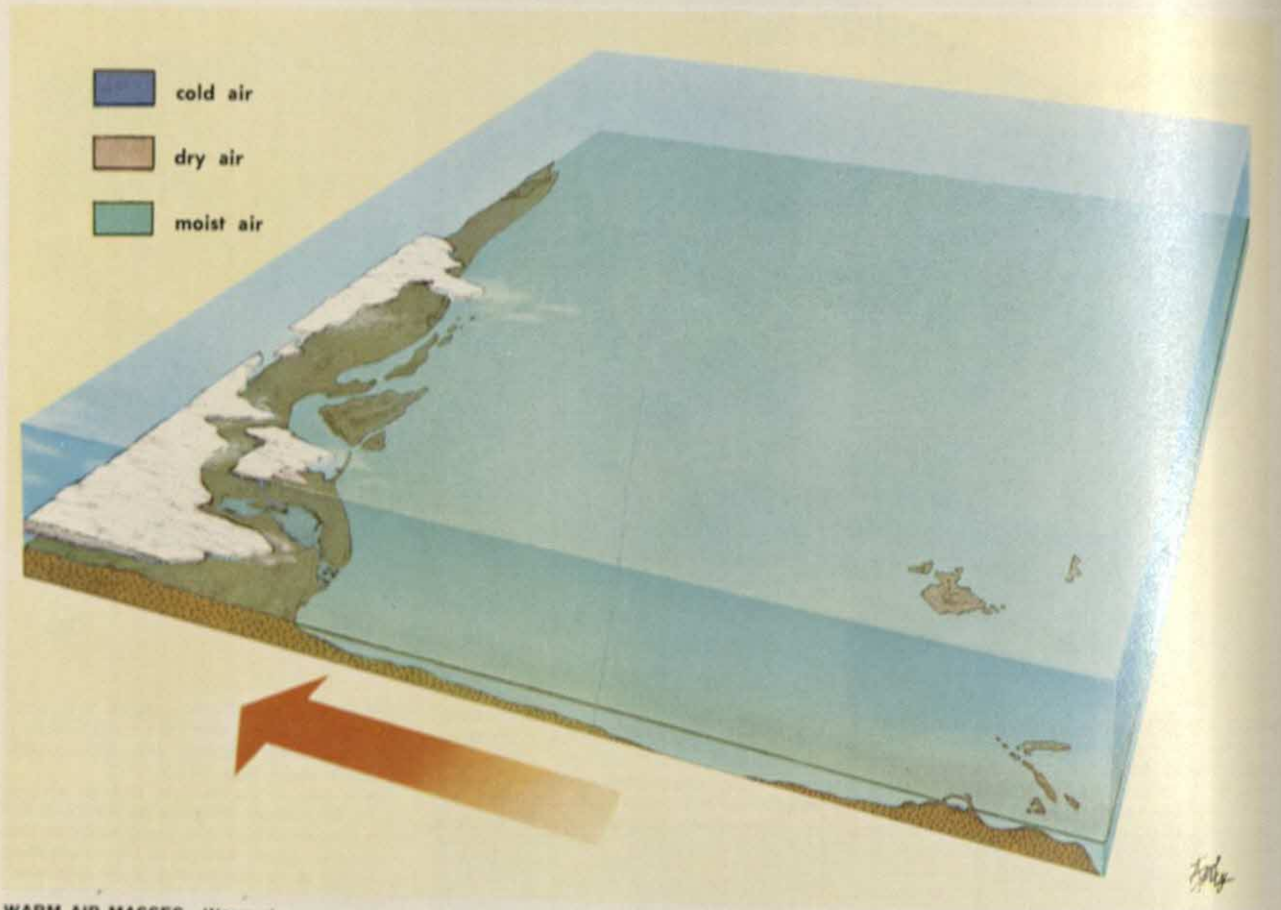
Weather forecasting—that much abused branch of meteorology—is based on an understanding of thermodynamic forces and their evolution in air masses. It requires a knowledge of cloud cover over different regions of the Earth and a knowledge of the type, direction, and speed of wind systems. Moreover, it requires a knowledge of the origins and the temperature and humidity characteristics of air masses, an accumulation of data concerning the regions over which and toward which air masses are moving, and an understanding of phenomena that occur when one air mass encounters another.

The weather forecasts that are transmitted over the radio as aids to marine and aerial navigation are made by correlating and analyzing data collected at thousands of weather stations and recorded on weather charts or maps. Anyone who has access to up-to-date weather maps and who understands the characteristics of weather systems and the laws governing their movements can make fairly accurate weather forecasts.

When a great mass of air remains stationary for a period of time in a given region, it acquires certain thermodynamic characteristics that it tends to retain for a relatively long time, even though it moves from that locality. For example, a mass of air that has remained for some time over a tropical desert is heated greatly by the ground; moreover, it is comparatively dry. Such so-called tropical air masses tend to move toward cooler regions, while air masses that have re-

3

a



WARM AIR MASSES—Warm air masses originate in the tropics; therefore, wherever they move, they encounter cooler conditions—the reverse of outflowing polar air masses. However, a tropical air mass can have one of two different sources: if it forms over a tropical sea, it is moist; if it forms over land, it is relatively dry. The former is known as a maritime tropical air mass, and the latter, as a continental tropical air mass.

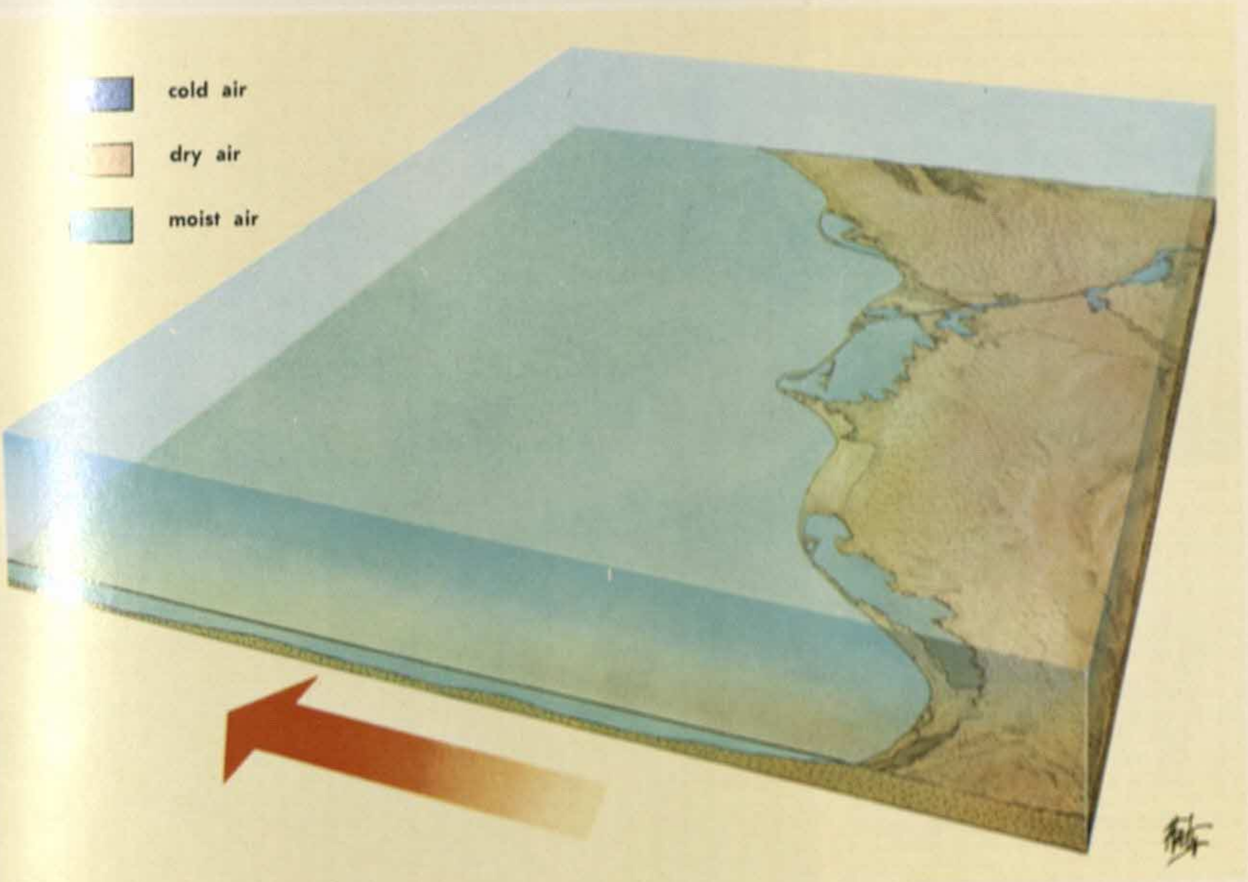
Maritime air masses (Illustration 3a) characteristically have extremely high moisture content, but they are not overheated from contact with the Earth's surface, which, consisting of water, is always relatively cool. In the tropics the troposphere extends as high as 16,000 m (about 52,500 ft); consequently, even when the ground temperature is relatively high, the temperature gradient of an air mass is modest.

As a warm air mass moves toward higher latitudes, the layer that is in contact with the ground cools most rapidly, thereby diminishing the temperature gradient further at low altitudes. However, the air mass, which has a very high moisture content (both absolute and relative), quickly becomes saturated as the temperature drops; condensation, cloud formation, and finally precipitation occurs, as shown at the left side of the drawing.

mained for a long time near the Poles (so-called polar air masses) always move toward warmer regions.

Moving air masses undergo changes in temperature and humidity, depending on the nature of the surface over which they pass. A cold air mass moving over warm land, for example, tends to become warmer. An air mass moving over the ocean tends to acquire moisture.

Air masses characteristically have great horizontal extension, but little vertical extension. Therefore, when air masses of different temperatures meet, they do not mix; instead, for example, when a warm air mass meets a cold air mass, the cold mass wedges under the warm mass, lifting it up. The interface between these two adjacent air masses is known as a front. Weather changes ordinarily occur along a front, because the upward movement b



Extensive hot, dry continental air masses (Illustration 3b) originate in only one major part of the world—North Africa, where the vast Sahara Desert heats the air tremendously. The lower layers of an air mass over the Sahara may reach a temperature of 50° C (122° F), causing a wide temperature gradient. The superheating of the air is accompanied by a lowering of both relative and absolute humidity.

As a mass of continental tropical air moves away from the source region, the gradient at the ground diminishes because the upper layers cool rapidly. Even if the relative humidity increases slightly and the absolute humidity not at all, the air mass can undergo intense cooling without condensation.

Except along its southern boundary, the Sahara is close to the sea in all directions, and the masses of air formed over this desert characteristically pass over regions of water. Consequently, the moisture content of these air masses increases greatly as they move away from their source region. Being very hot and very dry, these masses have the capacity to absorb a large quantity of moisture, which they frequently do. If migration is rapid, however, they may travel for great distances without changing their high pressure, high temperature, and low moisture content.

of the warm air mass results in condensation of moisture, the formation of clouds, and precipitation.

By analyzing weather maps showing the characteristics of air masses in a particular region, meteorologists can deduce the direction in which the front will move and, therefore, can forecast weather changes likely to take place in different localities.

Weather forecasting as a public service is only about 100 years old. Only after the invention of the electric telegraph did it become possible to establish communication systems suitable for the rapid collection of weather reports. The first systematic experiments in weather telegraphy and forecasting began in about 1860 in England, France, and the United States. A decade later, several other countries had such service.

THE CIRCULATION OF SUBTERRANEAN WATER

cave formations in calcareous and dolomitic rocks

1

KARST SINKHOLE—Karst areas are underlain by rocks of sedimentary origin and are, therefore, characterized by layered formations. The boundary between layers forms the line of attack for watercourses that can quickly transform a fine fracture into a broad channel. As time passes and the water does its work, the channel widens and eventually a cave of large dimensions may be scoured out.

A sinkhole is an opening in the cave's roof in which the water collects before starting its voyage underground. An area such as that illustrated is often perforated by a number of caves and covered by several sinkholes, each of which collects rainwater. Even small amounts of water eventually enlarge these sinkholes, so that older ones turn into large depressions.

Water is necessary for life. It is used for drinking, washing, and countless industrial tasks. Water can also flood the land, destroy cities, and drown people. In addition, water can work quietly and calmly to change the face of the Earth.

Much of the work that water does is underground. Over the centuries, calcareous and dolomitic rock is often dissolved by water, thus forming caves that give rise to the phenomenon of subterranean water circulation.

Calcareous mountains are often perforated by a complex network of caves, making it possible for large underground streams to flow at high speed through such mountains. Some underground rivers are completely hidden from view for a large part of their courses. A river that is visible for great lengths may suddenly become an underground river, flowing deep inside the mountain.

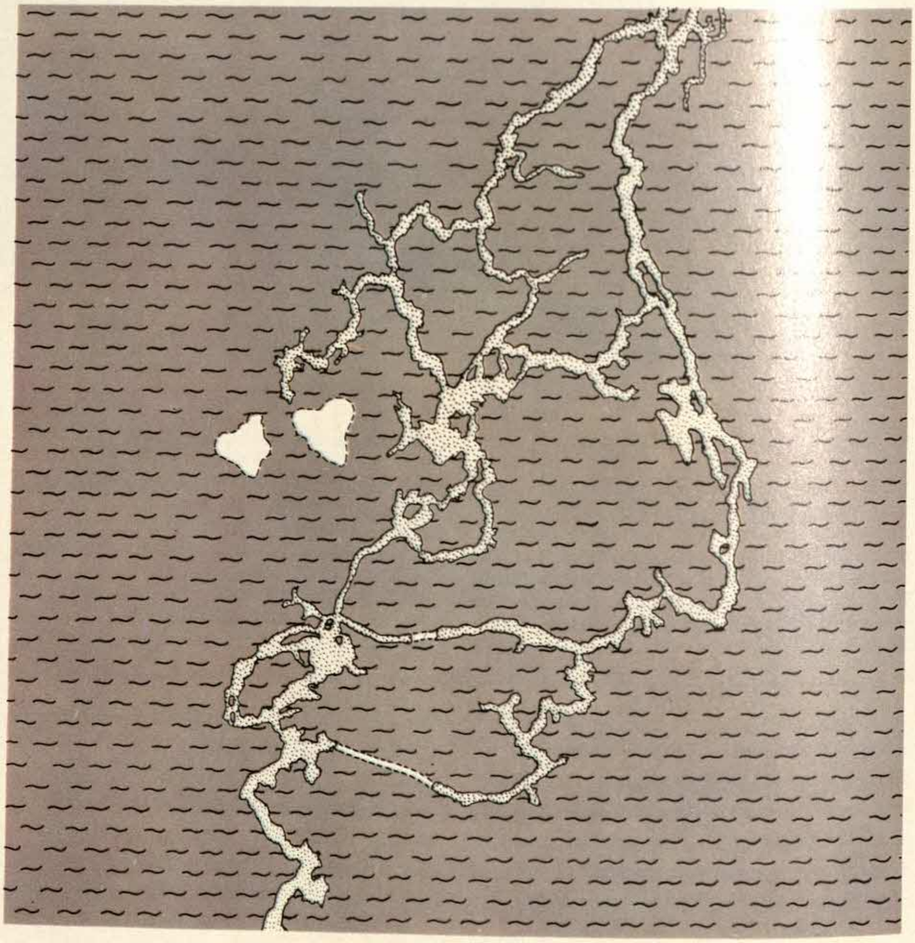
Cave exploration, or spelunking, is a popular hobby. Some caves have been opened to the public, usually for a fee, and these offer safe observation for the beginner. An allied subject, not as glamorous perhaps but rewarding for the scientist, is identification of subterranean streams before and after their disappearance underground.

THE IDENTIFICATION OF WATERCOURSES

In karst regions—areas typified by soluble bedrock, usually limestone—even a large watercourse may be swallowed up by a system of underground caves, reappearing later when it reaches an area of im-

MAP OF A LARGE CAVE—The illustration shows the known areas of the huge Postumia cave in Italy. An underground watercourse has opened up immense halls in this cave. Many unexplored connecting chambers are not shown.

2



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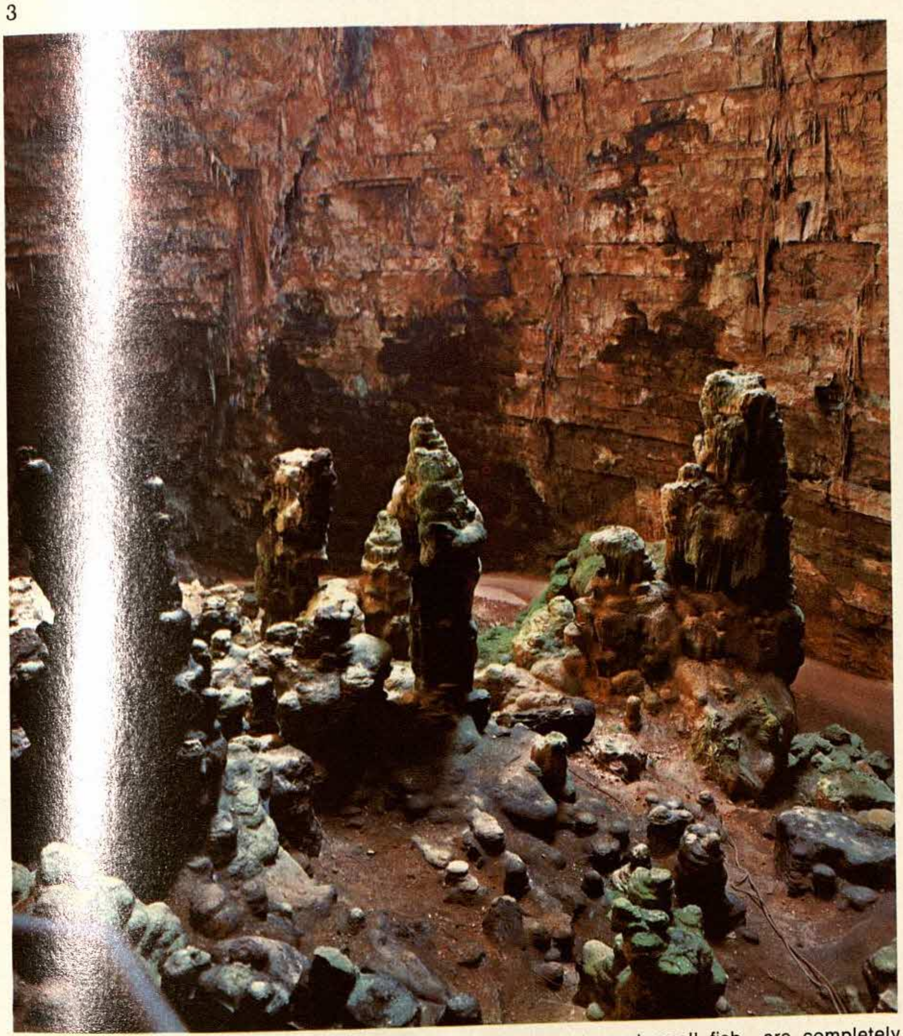

CAVE LIFE—Some sunlight penetrates this cave entrance. A little further inside, darkness is complete; consequently, no vegetation exists, and the few examples of animal life—some insects and small fish—are completely blind.

In this cave entrance, some of the outcroppings are covered with vegetation.

permeable rock. At times it is easy to determine whether the re-emerging watercourse is the same that disappeared previously.

When a large mass of rock is perforated with a number of caves, numerous streams may intermingle within the rock mass. When water enters the rock mass at different entrance points, is mixed inside with other watercourses, and is redistributed through various exits, there is no way of establishing identity between watercourses. This situation is the exception, not the rule, however.

Several methods are used to establish the identity of watercourses; some are available only to the professional, while others are within the reach of the amateur.

The easiest method requires only a thermometer. If it can be established that the temperature of the watercourse is the same at the entrance and the exit, it is reasonably certain that the two

STALACTITES AND STALAGMITES—Two common phenomena in caves are stalactites and stalagmites. Resembling icicles, the former hang from the ceiling, while stalagmites point up from the cave floor. Both are formed by calcium-saturated water dripping from the roof of the cave. Usually, the water contains a high percentage of carbon dioxide. The CO_2 dissolves, leaving the calcium behind. The calcium carbonate may attach itself to the roof, forming a stalactite, or to the floor, forming a stalagmite. Very often, stalactites and stalagmites grow together, forming solid columns from floor to roof.

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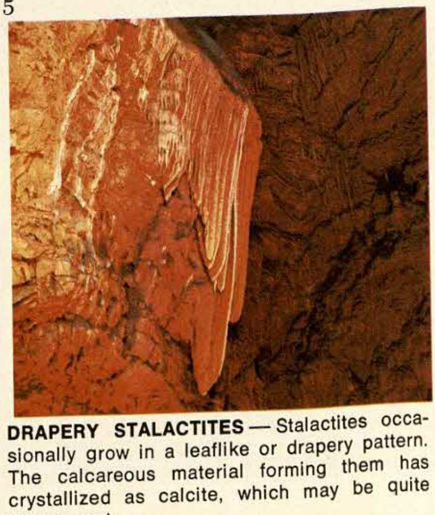
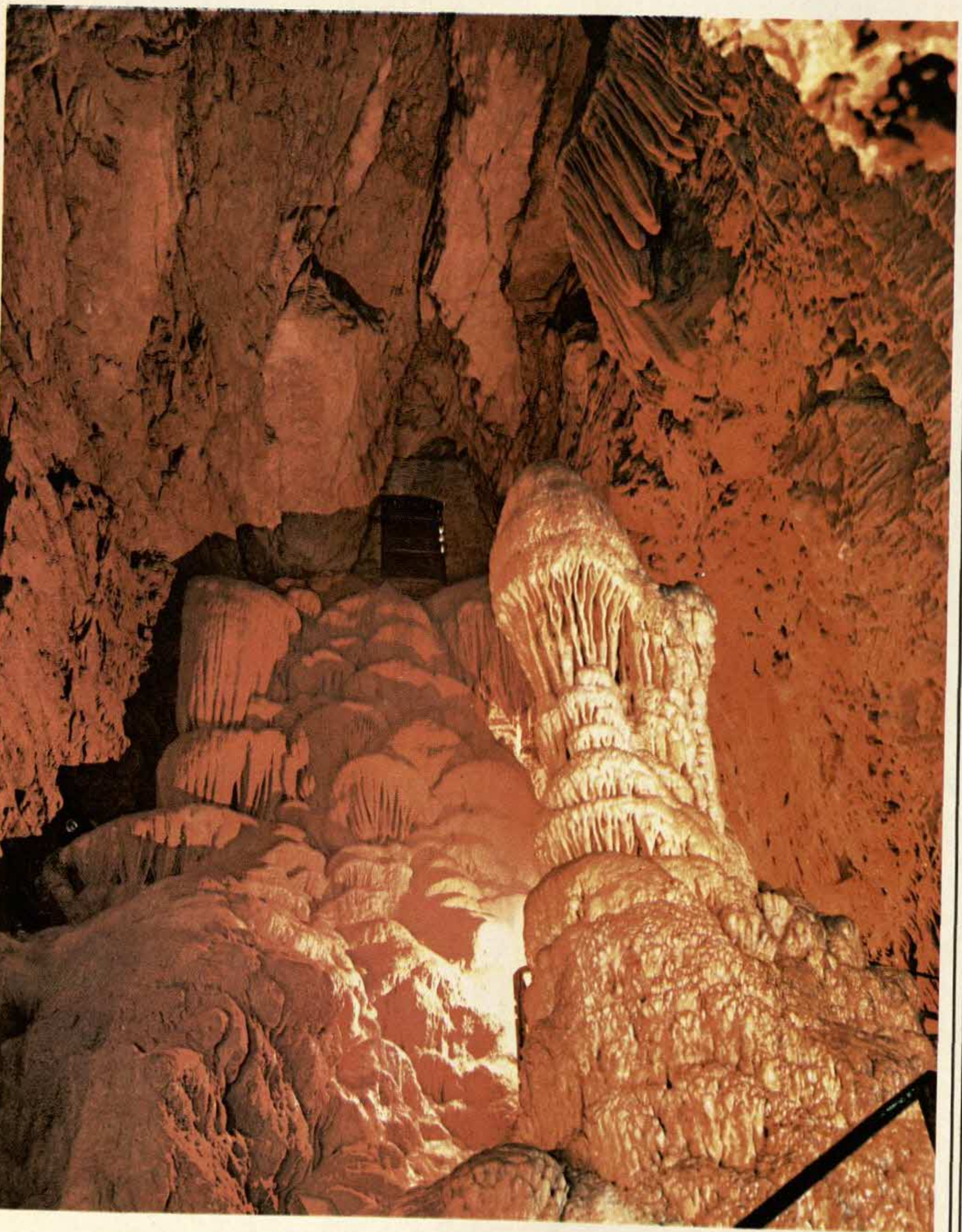


DRAPERY STALACTITES — Stalactites occasionally grow in a leaflike or drapery pattern. The calcareous material forming them has crystallized as calcite, which may be quite transparent.

6



BIRTH AND DEATH OF A CAVE—The water that formed this cave now threatens to close it. In a few centuries, the enormous stalagmite will grow big enough to fill this section of the cave. Thus, the percolating water will eventually cause the death of the cave it created.

A similar process works on man-made structures of calcareous material. Beneath the Lincoln Memorial in Washington, for example, hang stalactites that have formed from the limestone in the Memorial, even though it is only a few decades old.

7

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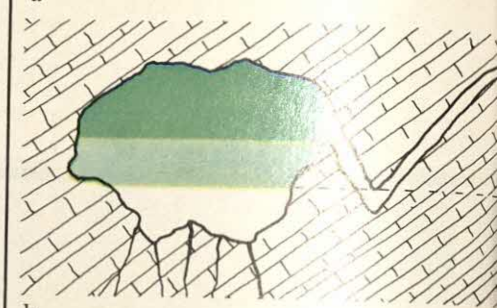

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WATERCOURSES AND SIPHONS — A major difficulty in exploring caves is the constant change from one level to the next. Moreover, the water levels often change abruptly. A section may be bone-dry at one time, then filled with water after a rain.

A siphon (Illustration 7a) is a chamber with an outlet. At times a siphon is completely filled with water, which gradually drains off until the next rainfall fills the chamber.

Cave explorers must keep the water level in the cave constantly in mind. The careful spelunker selects his exploration time carefully, so that he can proceed without the problem of high water. A cave that is ordinarily dry may become a torrential watercourse after a heavy rain.

Illustration 7b shows how clear the water can be deep inside a cave. This pool is so clear that it is difficult to distinguish the waterline even under bright light.

8

A DISAPPEARING RIVER — Illustration 8a shows how a river can run normally until it hits calcareous rock; it then plunges underground. The river illustrated flows underground until it reaches the sea. It could reappear if it ran into impermeable rock again. The river in this example runs through a series of caves.

Illustration 8b shows the same river entering the sea from under the rock.

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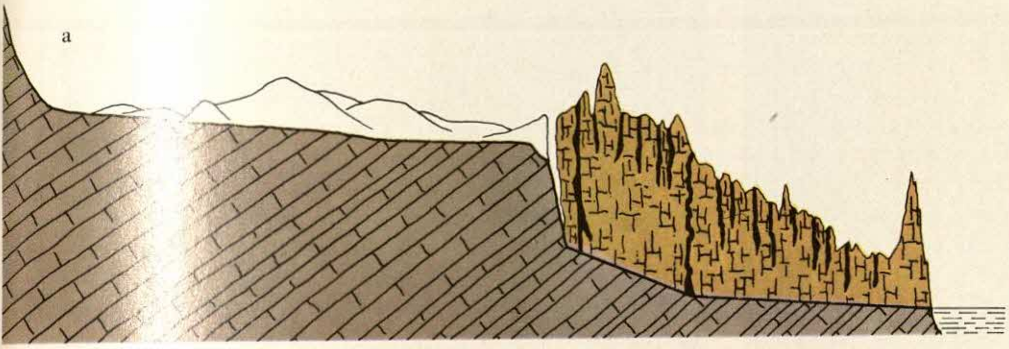

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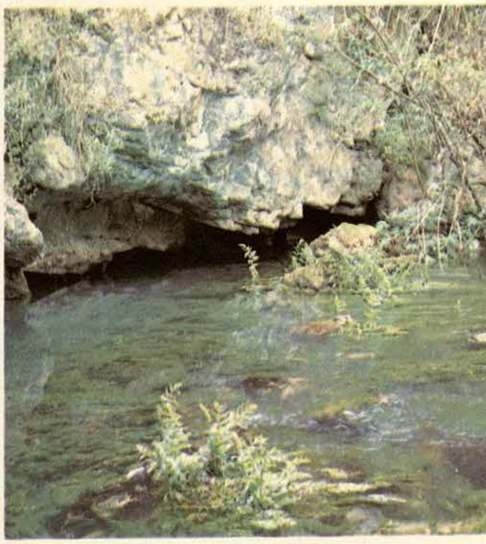

points of measurement belong to the same watercourse. Another good method is to put something in the water that can be traced, such as a stick or a sealed vessel of some kind. Some type of temporary pollutant may also be used, but this method is somewhat risky if the pollutant reduces the potability of the water. The substance must be resistant to the pH of the water and must not be too readily diluted. Fluorescein, probably the best substance for this method, can be recognized, even when extremely diluted, under fluorescent light.

Another excellent method of identifying watercourses is analysis of the saline components. This method requires a well-equipped laboratory. Water samples from the suspected entrance and exit points are analyzed. The same saline percentages at both ends establish quite clearly that the water comes from the same stream.

CAVES AND MAN

Ever since the first humans lived in them, caves have been popular places to explore. Archaeologists search the detritus of cave floors for tools or weapons of prehistoric men. Zoologists find in caves unusual forms of animal life, such as blind fish and amphibians.

It is highly recommended that the nonprofessional stay away from nonpublic caves. Unguided cave tours are the province of explorers with special skills, equipment, and an expert knowledge of the mountaineer's techniques of ascent and descent. Also required is a good knowledge of geology, which helps identify the potential dangers of unstable rock. A false step inside a cave may cause an avalanche that may seal in the careless spelunker.

The cave explorer must also be able to draw detailed maps and to recognize the ground already covered. It is easy to get lost in a cave. Furthermore, the level of an underground watercourse may vary with great rapidity, so that passages that were easy to get through on the inbound journey may be totally impassable on the return.

Unexplored caves rarely contain attractions not visible in caves that are open to the public. These caves are abundant throughout the world wherever calcareous bedrock occurs. The public caves are equipped with guides, lights, footpaths, stairways, ropes, and other conveniences that provide a safe and instructive experience.

The world's most famous cave area is in the calcareous Alps of central and southern Europe, stretching from France through Switzerland and Austria to Yugoslavia. Among the best known caves in the United States are Carlsbad Caverns (New Mexico), Mammoth Cave (Kentucky), and Luray Caverns (Virginia). There are also well-known caves in the Himalayas, in Malaya and Indochina, in South Africa, and in Australia. Windsor Cave in Jamaica is famous for its multitude of bats.

UNUSUAL CRYSTALLIZATIONS — This illustration shows some very fine calcite monocrystal formations (aragonite makes similar formations) that are possible only where the watercourse flows at an extremely low speed.

UNDERGROUND WATER | how water runs through the subsoil

Much recent interest has been focused on exploring the waters of the ocean's depths. Just as important, however, and equally fascinating, are the watercourses that flow beneath the ground. A high degree of skill and geological knowledge is required just to find these hidden waters. The factors governing their flow through soil and rocks must be understood so that this valuable water supply can be tapped for human and industrial purposes.

In general, the study of subterranean watercourses is based on geological and geomorphological considerations. Knowledge of the lithological structure of the ground—that is, whether it is permeable or impermeable, and at what angle the rocky strata are inclined—is essential for predicting the presence of underground watercourses.

The angle of the strata determines the descent of surface water into the deeper strata of the soil. The morphology of the ground and the geological characteristics of the subsoil determine the ease of water movement, the size of the basins in which it collects, and the possibilities of an exit point from underground in the form of a spring.

THE ORIGIN OF UNDERGROUND WATER

In terms of origin, underground waters can be roughly divided into two general categories. First, there is water that has been in the rock strata since its chemical creation. This category includes both water formed by the condensation of vapors escaping from volcanic magma, and water enclosed in crystals from the time that they were formed. The water of thermal springs, for example, is most often young water that has newly emerged from the magma in which it

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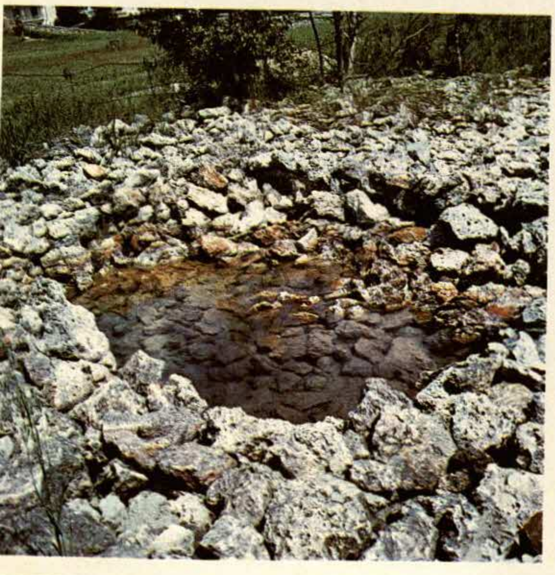

YOUNG WATER—The vapor that condenses at the exit of a volcanic blowhole (Illustration 1a) or a thermal spring (Illustration 1b) is an example of water just freed from the magma in which it was formed and imprisoned. This is young water, just entering into the cycle of subaerial and underground circulation. Water in a quartz crystal is seen in Illustration 1c.

c

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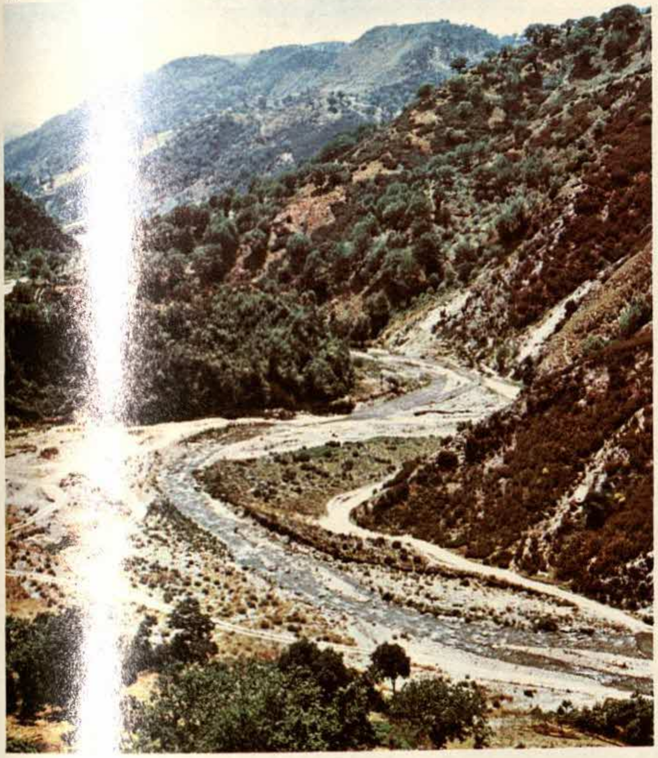

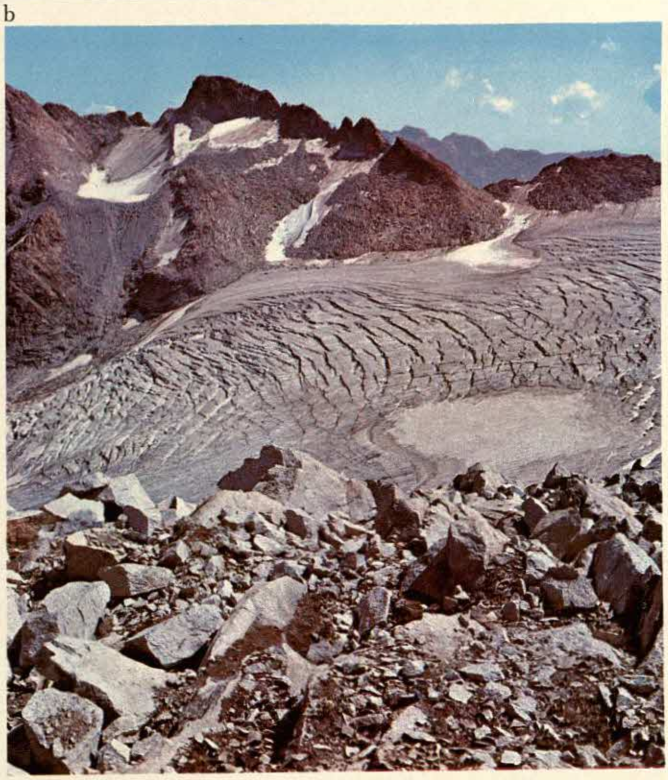

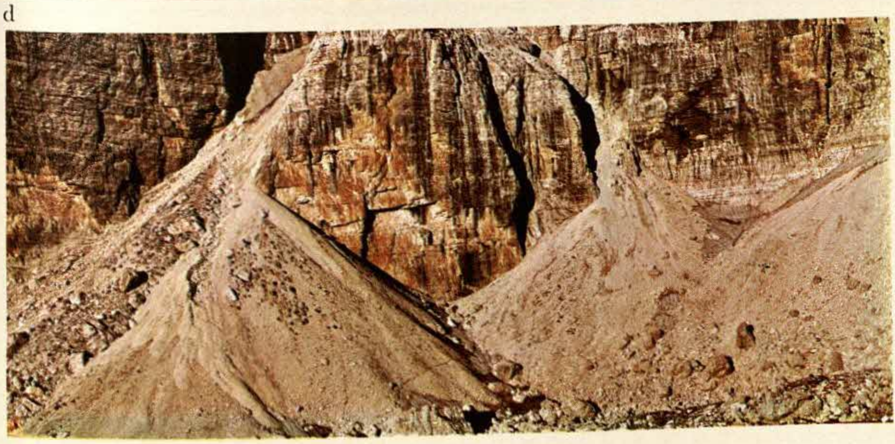

EXAMPLES OF PERMEABLE TERRAIN—Certain types of permeable terrain can be recognized even when they have been masked by subsequent geological events.

Soils formed from river floods are composed of fine sand or medium or large gravel or both (Illustration 2a). Such alluvial deposits are extremely porous and often quite permeable; they also have a high capacity for percolation. Sometimes, floods create deposits of vast extent; the huge Mississippi Delta, for example, is of alluvial origin. These deposits may, however, alternate with layers of clay that block the passage of water.

Morainic rock (Illustration 2b) may be even more permeable than alluvial deposits. It consists of the morainal refuse of an ice field, and is deposited at random.

A recently formed moraine is easily recognized, especially if it is still uncovered and surrounded by the ice field. However, this is more difficult with an ancient moraine where the ice field no longer exists and the area is covered with vegetation or has been attacked by erosion that has altered its shape and dimensions.

Sand dunes (Illustration 2c) consist of highly porous matter.

The cone formed by soil after a landslide is always rather porous. Illustration 2d shows a large Alpine cone composed of extremely porous rock.

These examples of terrain that is porous and often permeable are readily recognizable. Similar terrain formed in ancient times must be investigated to determine whether the underground passages have become blocked. If this is the case, their permeability may have been reduced or eliminated.

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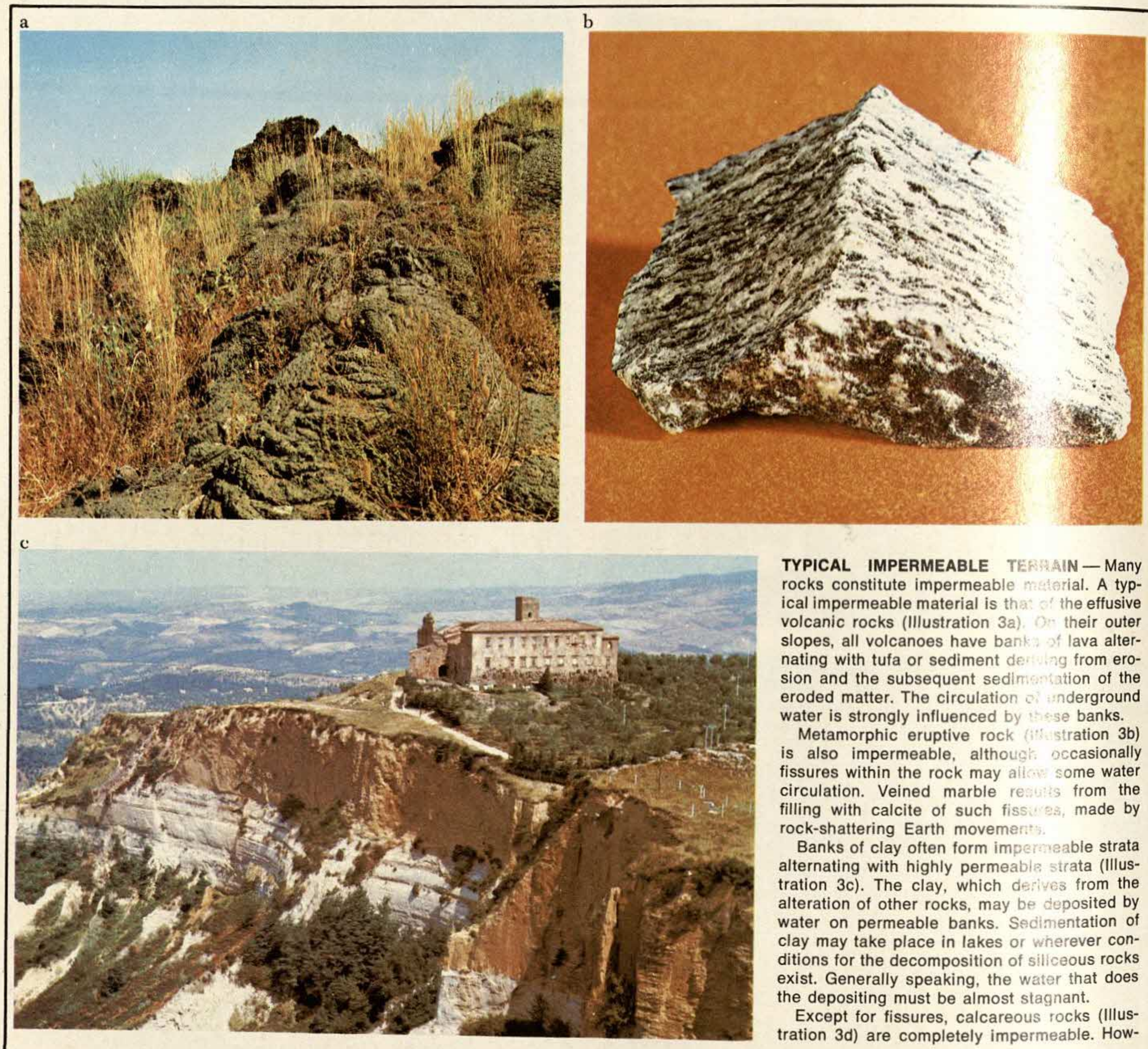

TYPICAL IMPERMEABLE TERRAIN — Many rocks constitute impermeable material. A typical impermeable material is that of the effusive volcanic rocks (Illustration 3a). On their outer slopes, all volcanoes have banks of lava alternating with tufa or sediment deriving from erosion and the subsequent sedimentation of the eroded matter. The circulation of underground water is strongly influenced by these banks.

Metamorphic eruptive rock (Illustration 3b) is also impermeable, although occasionally fissures within the rock may allow some water circulation. Veined marble results from the filling with calcite of such fissures, made by rock-shattering Earth movements.

Banks of clay often form impermeable strata alternating with highly permeable strata (Illustration 3c). The clay, which derives from the alteration of other rocks, may be deposited by water on permeable banks. Sedimentation of clay may take place in lakes or wherever conditions for the decomposition of siliceous rocks exist. Generally speaking, the water that does the depositing must be almost stagnant.

Except for fissures, calcareous rocks (Illustration 3d) are completely impermeable. How-

was dissolved, although, in rarer cases, it is water that has infiltrated the soil and become heated and enriched by mineral elements in the soil. Water encapsulated in crystals is a mineralogical curiosity, but has no bearing on research into the flow of subterranean watercourses.

The second category includes water that has a cyclical history—that is, the water comes from the atmosphere, enters the rock strata beneath the surface, and moves through it until it returns to the atmosphere and repeats the cycle.

Each year, about 0.5 m (about 1.5 ft) of water evaporates from the surface of the sea, falling back on the Earth in the form of rain—two thirds into the sea and one third on land. Some of this rainwater runs over the surface of the soil and is collected in rivers. The remainder penetrates the soil and begins an underground cycle. A portion of this water is soaked up by the surface soil, from which it re-evaporates slowly. Another portion is absorbed by the roots of plants, and is dispersed into the atmosphere by evaporation from leaves and low vegetation. Finally, a portion enters into the underground cycle.

SOME CHARACTERISTICS OF ROCKS AND SOILS

Rocks are permeable when water is able to pass through them. Such a rock may

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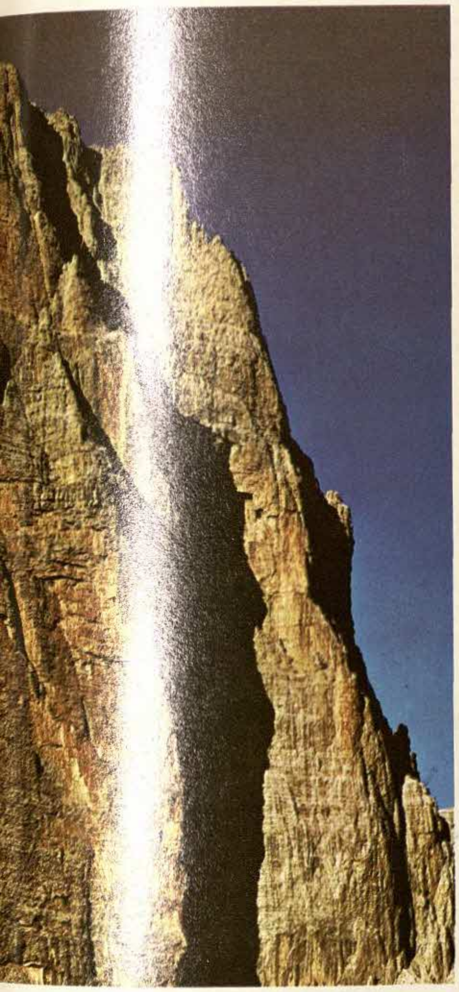

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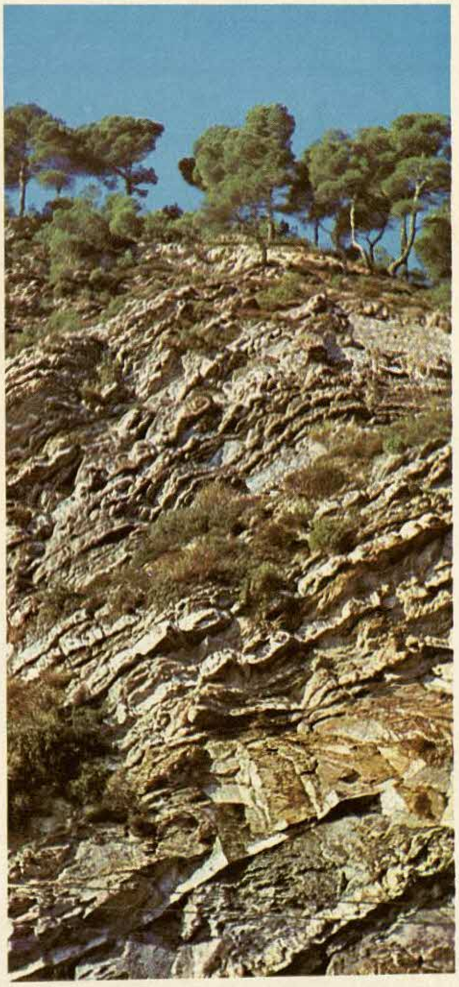


ever, limestone, for example, is usually well-jointed; and it is soluble in rainwater. The joints become enlarged as a consequence, and the rainfall is absorbed into the rocks and flows underground.

Such rocks as marl (Illustration 3e) and fine sandstone are impermeable in terms of the underground circulation of water. However, they are not necessarily impervious to the passage of water that, under certain conditions, flows through them quite slowly, causing the deposition and subsequent recrystallization of the rock. This extremely slow transformation of rock by water is due to its microporosity, but this is of little significance to the flow of underground watercourses.

be porous or fissured, or it may have channels within it. These properties must be investigated before it is possible to predict the reserves of water in a given rock layer or the characteristics of its underground circulation.

A porous, or at least permeable, soil absorbs water according to the physical and chemical properties of the rocks of which it is composed. An example is the upper layer of sand on the bed of a stream filled with water during a flood. When the flood is over and all the water has disappeared, some is still retained in the sand because of its power of absorption.

Certain soils are capable of absorbing water from the atmosphere because of their hygroscopicity. They take water from the atmosphere even when there is no rain.

In some instances, two equally porous soils have communicating pores that allow water to pass from one to the other. The water may flow through them at varying speeds.

Soil or rock strata that are sufficiently permeable to yield useful quantities of water to wells are known as aquifers. The upper surface of the zone of saturation is known as the water table. Artesian aquifers are covered by a stratum of impermeable material, and the confined water is under pressure, so that it will rise in a well to a level above the top of the aquifer and may even discharge at the ground surface without pumping. Where the water table intersects streams, lakes, or swamps, the groundwater is discharged and becomes surface water.

A spring occurs when the water table intersects the surface of the ground; a spring is the natural point of escape from an underground reservoir. In an area of completely permeable rocks, the springs issue at or near valley bottoms. When the area consists of alternating permeable and impermeable beds, each impermeable bed holds up water on its surface. If the strata are horizontal, small springs may appear all around the outcrops; if they are tilted or folded, however, the flow of the underground water will be toward the lowest point on the base of the permeable water-bearing bed. At this point, the main spring for that reservoir will be located.

In strata that are mainly impermeable but somewhat brittle, the presence of joints and cracks is important in determining the direction and amount of flow in the underground waters. In jointed rocks, the rainwater may sink to great depths down one set of joints and rise again along a second set, issuing at the surface as a thermal spring. When a permeable bed and an impermeable bed are brought into juxtaposition through faulting, the flow of water in the permeable bed is checked; but since faulting often shatters the rock, the faulting may afford a plane of weakness along which the water will tend to flow. Some of the largest springs issue from thick beds of massive limestone, which usually is well jointed. The rock being soluble in rainwater, its joints become enlarged; and the whole of the rainfall is absorbed in the rocks and flows underground to issue as large springs.

HARD WATER | the problems

Water is indispensable to mankind—first because nothing can take its place in meeting the physiological needs of animals and plants, and second, because it has made possible the development of many industries. The first reason needs no clarification; life as man knows it cannot exist without water. The importance of the second factor becomes apparent in the fact that many industries, such as the textile industry, came into being beside rivers and streams. In addition, water turns the turbines of hydroelectric plants that produce electricity for many industries.

Although the world's water resources are generally greater than its needs, their distribution differs greatly from one part of the Earth to another. In areas where water is plentiful, life flourishes, but in areas where water is scarce life itself is scarce, and industrial development is virtually impossible.

Whatever its source—the sea, rivers, lakes, deep springs, or wells—water is never pure. It always contains various amounts of dissolved salts, insoluble substances such as sand and mud in suspension, and even decomposed organic matter, all of which make it necessary for the water to be purified before being used.

A PAPER MILL ON A RIVER—Many industries that require large quantities of water in their manufacturing processes are located, for obvious reasons, along the banks of rivers.

A STEAM PIPING PLANT—The water used in a paper mill must have an especially high degree of purity so that the quality of the product is high. This illustration shows pipes that transport steam from the boiler plant to the paper mill.

The sea is not yet a major source of usable water because its high salt content makes its purification complex and costly. Nevertheless, seawater is now being purified on a modest scale in a few locations where land water is scarce. However, seawater is used to economic advantage in the cooling plants of industries located close to the sea, especially those requiring huge quantities of water for cooling. In such cases, the water is used with little treatment beyond the addition of chlorine (Cl_2), which prevents the growth of bacteria.

This discussion is limited to fresh water and the impurities found in it. The following paragraphs consider the problems caused by these impurities, with particular emphasis on the problems caused by the presence of dissolved salts. Some of the methods used to reduce those impurities to acceptable limits are described briefly.

The surface waters of certain rivers and lakes sometimes appear turbid and musky. The turbidity is due to insoluble materials held in suspension, such as mud or minute detritus of minerals carried along by the current, while the coloration is due to the presence of decomposed vegetable matter. In any system of water distribution these two factors must be controlled in order to avoid excessive deposits. Drinking water must always be clear; the law requires that its content of substances in suspension be kept at a minimum. Some industries require water even purer than drinking water; in a paper mill, for example, the presence of any extraneous matter in the water used would compromise the quality of the paper produced.

Dissolved salts are also a harmful element in water, and much more troublesome than other impurities. These salts, which are mostly in the form of carbonates, bicarbonates, chlorides, sulfates, and so forth, are picked up by the water while it is percolating underground. Calcium (Ca) and magnesium (Mg) salts, and especially the sulfates and carbonates of these salts, are particularly harmful because they make water "hard."

A WATER SPRING—Whatever its source, water is never pure but contains larger or smaller amounts of salts. A natural water spring is illustrated.

INCRUSTATIONS DUE TO HARD WATER—Evaporation of water by heat results in precipitation of calcium and magnesium salts.

Water is said to be hard when it has a high content of dissolved calcium and magnesium salts, and soft when it has a low content of such salts. It is possible to be even more precise and distinguish between temporary hardness, which is the hardness caused by the bicarbonates of calcium and magnesium, $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$, and permanent hardness, which is the hardness caused by all other calcium and magnesium salts. The sum of these two hardnesses is the total hardness of the water.

The hardness caused by bicarbonates is called temporary hardness because the bicarbonates decompose when water is heated and give rise to far less soluble carbonates according to the equation

$$Ca(HCO_3)_2 \rightarrow CaCO_3 + CO_2 + H_2O.$$

In general, heating brings about a change in the conditions of solubility of the salts in water; the salts become more and more concentrated as the water evaporates and begin to precipitate when the saturation point is reached, thereby giving rise to the formation of more or less compact incrustations. If this process occurs in a boiler used for producing steam, it creates two problems that become increasingly difficult as the working pressure of the boiler increases: first, the incrustation causes a reduction in the coefficient of heat exchange across the metallic walls of the boiler, and this reduction leads to a loss of efficiency; second, the temperature of the walls of the boiler may be raised to such an extent as to endanger the mechanical stability of the boiler.

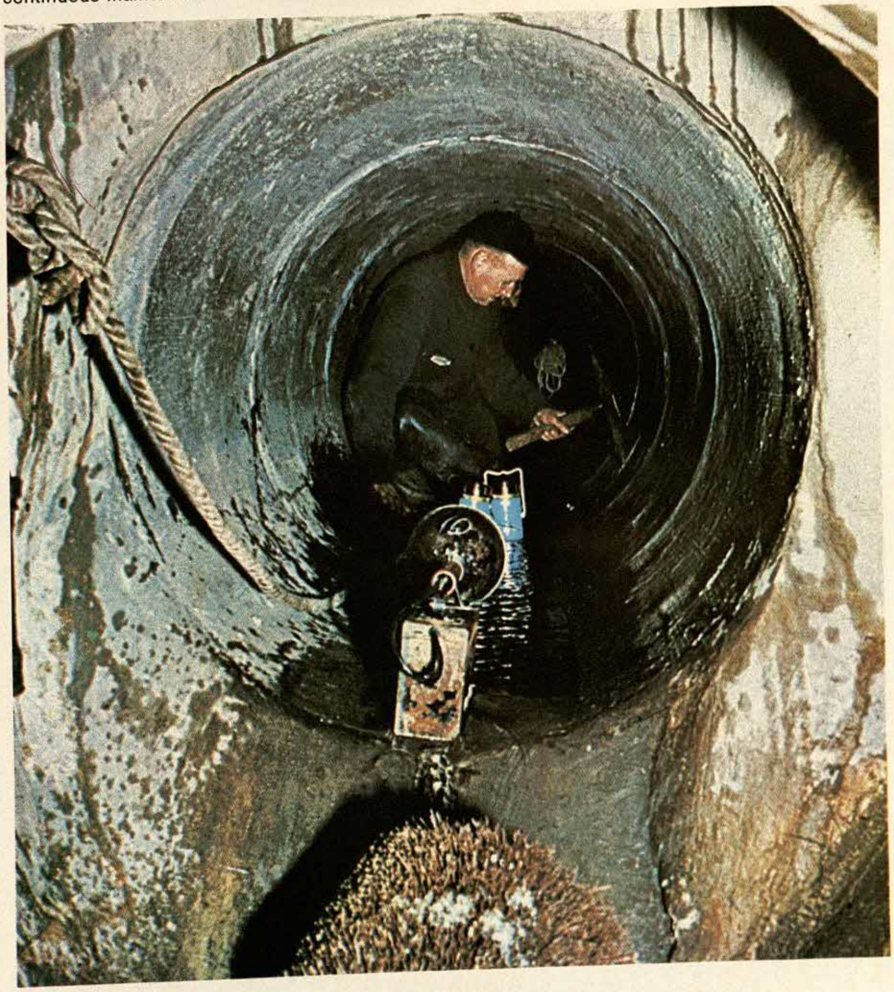
In order to understand this phenomenon, it must be kept in mind that heat is transmitted across a metal wall (a boiler tube) according to the following law:

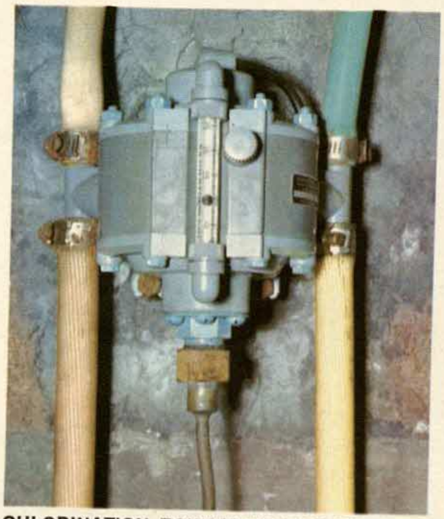
$$Q = \frac{K \times A \times (t_1 - t_2)}{h},$$

where Q is the heat transmitted to the water by the products of combustion, K is the coefficient of thermal exchange across the metal wall, A is the heat exchange surface of the boiler, t_1 is the temperature of the products of combustion, t_2 is the temperature of the water to be evaporated, and h is the thickness of the metal wall.

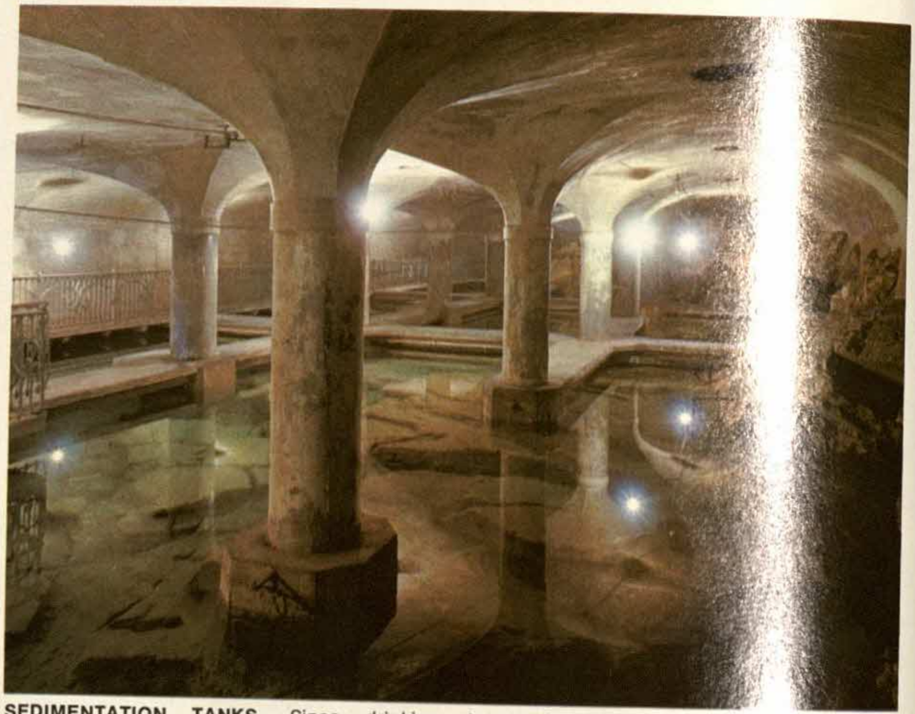
If the water deposits a certain layer of salt on the metal wall (salts are poor conductors of heat), the heat needed for the evaporation of the water must cross both the thickness of the metal wall and the additional thickness of incrustation.

INSIDE AN AQUEDUCT—All aqueducts need continuous maintenance to eliminate the harmful deposits or incrustations left by the salts contained in water.





CHLORINATION EQUIPMENT FOR DRINKING WATER—Both drinking water and water for industrial use must be chlorinated to prevent the growth of bacteria.



SEDIMENTATION TANKS — Since drinking water must be clear, all suspended matter such as mud and detritus must be eliminated from it. To accomplish this, water is allowed to stand in sedimentation tanks where the heavier microscopic particles settle to the bottom.

In view of the fact that heat can only be transmitted when a thermal gradient exists between the two sides of the wall across which the heat is being transmitted, the contact surface between the metal and the incrustation must necessarily attain a temperature (t_x) that is greater than the temperature (t_2) of the water. The result is that the temperature of the boiler tubes becomes greater and greater as the thickness of the incrustation increases, and this increase leads to a reduction of the mechanical resistance of the tubes. In the case of high-pressure boilers, where the working temperature is already high, the formation of incrustations could lead to overheating to such an extent that the tubes would break.

Among other impurities found in water are the dissolved gases oxygen and carbon dioxide. These gases cause water to have a corrosive action that becomes more and more pronounced as the temperature of the water increases. This corrosive action can be explained briefly as follows: when in contact with water, iron tends to pass into solution in the form of bivalent ions, Fe^{2+}; and, since iron is less noble than hydrogen, iron displaces hydrogen ions from the solution (the hydrogen ions are obtained from the dissociation of the water according to the equation $H_2O \rightleftarrows H^+ + OH^-$) and leads to the formation of gaseous hydrogen:

$$Fe + 2H^+ + 2OH^- \rightleftarrows Fe^{2+} + 2OH^- + H_2.$$

The hydrogen obtained from this reaction forms a kind of protective film on the surface of the iron, that is, on the metal sheet or tube in contact with the water, and prevents any further solution of iron. The solubility of iron in pure water is, therefore, altogether negligible. However, if the water contains any dissolved oxygen, the hydrogen will be oxidized to form hydroxyl ions (OH^-); the protective film is thus removed from the iron, and the reaction proceeds even further. The bivalent Fe^{2+} first becomes oxidized and forms trivalent Fe^{3+}; it is then precipitated as ferric hydroxide, $Fe(OH)_3$, a salt that is only very slightly soluble. The phenomenon of the dissolution of iron therefore continues as long as oxygen is present in the water.

Carbon dioxide also plays an active part in the corrosion of iron, according to the following reactions:

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \rightleftarrows \underset{\text{carbonic acid}}{H_2CO_3},$$

and

$$Fe + 2H_2CO_3 \rightleftarrows \underset{\text{ferrous bicarbonate}}{Fe(HCO_3)_2} + H_2.$$

In this case again, the dissolution of the iron causes the displacement of hydrogen from the solution. If the water also contains oxygen, the hydrogen becomes oxidized to OH; oxidation of the iron and hence decomposition of the ferrous bicarbonate occur, followed by precipitation of ferric hydroxide. The decomposition of the ferrous carbonate liberates carbon dioxide, which starts its corrosive action all over again.

THE DEMINERALIZATION OF WATER

water for industry

Depending on its source, water contains impurities that differ perceptibly in both quality and quantity. Depending on the use for which the water is intended, these impurities must be reduced or removed entirely. For industrial use, water need be purified only enough to make it suitable for a specific purpose.

The first and generally indispensable step in purifying water is clarification, achieved by separating out the materials in suspension. Clarification can be by simple sedimentation, filtration, or a combination of the two methods.

Sedimentation takes place in large tanks, through which the water moves very slowly so that the particles in suspension accumulate on the bottom through gravity. Sometimes coagulants are added—substances such as aluminum sulfate, $Al_2(SO_4)_3$, ferric chloride, $FeCl_3$, and polyelectrolytes that exert a chemical and physical effect on the suspended particles to accelerate separation.

Reacting with the bicarbonates present in solution, aluminum sulfate changes into aluminum hydrate:

$$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4 + 6CO_2. \quad (1)$$

This forms a precipitate that tends to trap the smaller particles, causing sedimentation that would not otherwise take place.

If the degree of clarification obtained by sedimentation is not sufficient, filtration, the mechanical method of separating suspended particles, is used. Filters work by either gravity or pressure. The gravity type is commonly used to filter large quantities of water, as in municipal purification plants. The pressure type can be inserted directly into the distribution network, eliminating the expense of further pumping after filtration.

Gravity filters are generally large open tanks with a filtration bed consisting of successive layers of various-sized granular materials. From the bottom up, the materials used might be pebble gravel, crushed stone, and sand. The water runs through the bed from the top downward, depositing practically all suspended particles.

When enough impurities have been deposited on the filtration bed to slow down the rate of filtration beyond a perceptible point, the filter must be cleaned. The water and the surface deposits are removed and the filtration bed is washed by passing water through it from the bottom up, eliminating particles trapped in the filter.

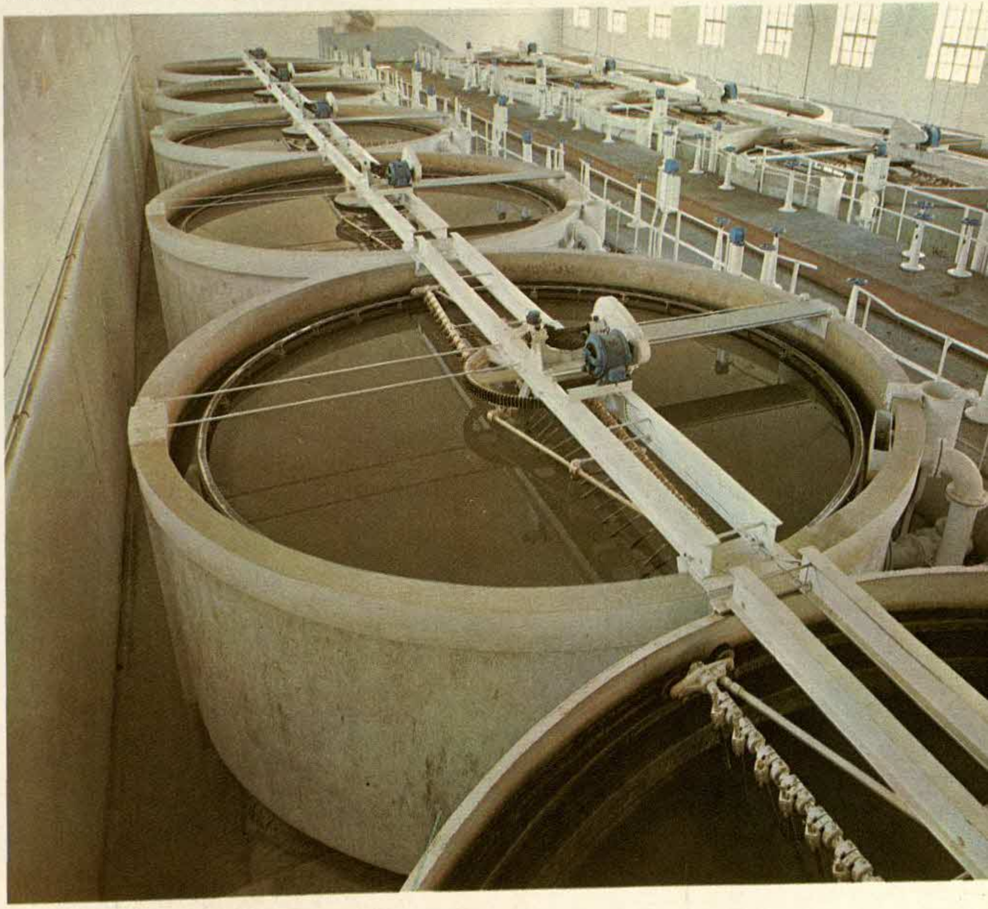
Another stage in purification is the elimination of hardness in the water. This is especially important if the water is to be used industrially, for hard water causes undue wear on machinery and equipment. Various methods for eliminating hardness are used; the methods differ in the degree of hardness that they eliminate, and are as follows:

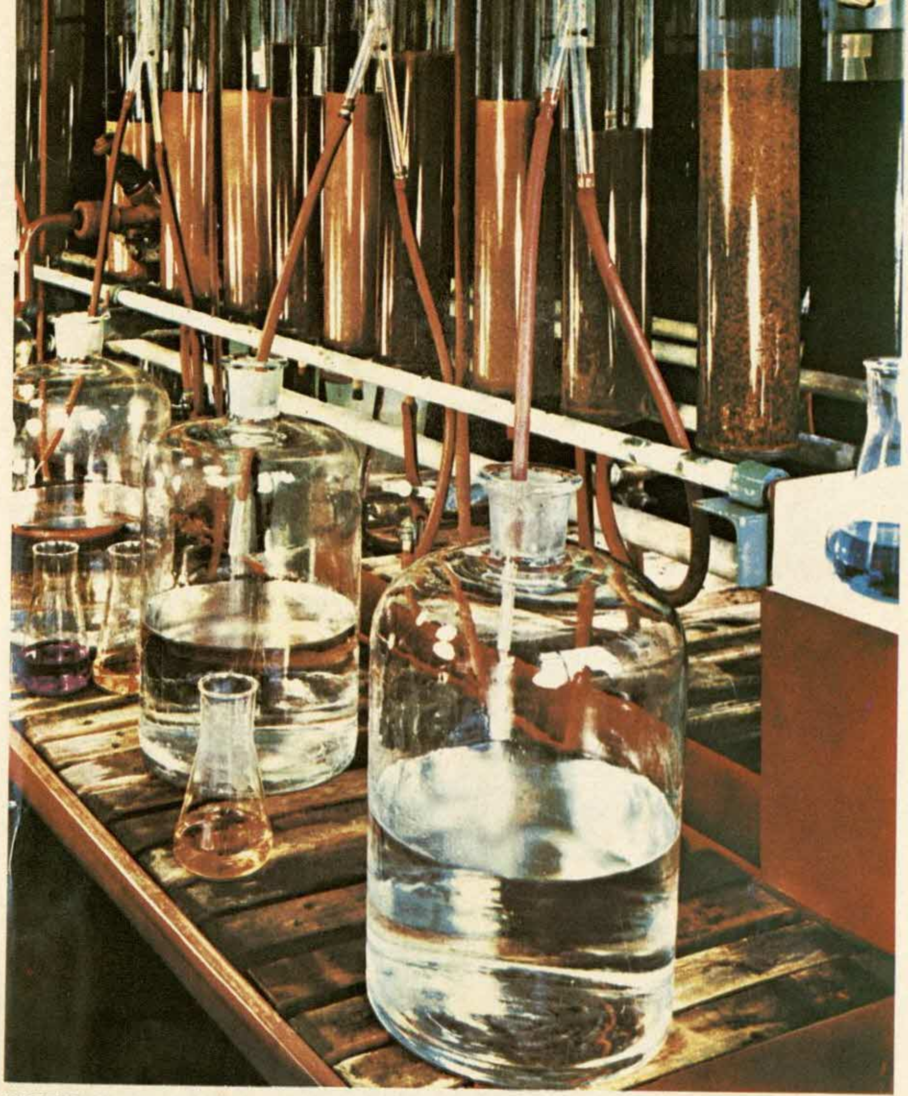
1. Heating the water before use causes decomposition of the calcium and magnesium bicarbonates that precipitate as carbonates, reducing temporary hardness.

2. Addition of disencrusting substances such as sodium carbonate (Na_2CO_3) stops the formation of hard encrustations in boilers, caused by the

WATER FILTRATION—Purifying water for industrial uses is of enormous importance. Water always contains rather large quantities of particles in suspension. To remove these particles, the water must either be decanted or filtered in tanks such as those shown here.

1





ION-EXCHANGE RESINS—Ion-exchange substances have made it possible to overcome complex purification problems. This photograph shows a laboratory for the purification of water by means of ion-exchange resins.

precipitation of calcium and magnesium sulfates through the concentration of the water after evaporation. Adding sodium carbonate directly to the boiler reduces permanent hardness caused by sulfates, chlorides, and calcium and magnesium nitrates:

$$\begin{aligned}&Na_2CO_3 + CaSO_4\\ &\quad\rightarrow CaCO_3 + Na_2SO_4. \quad (2)\end{aligned}$$

The water in the boiler must be continually drained and replaced in order to remove the precipitates of calcium carbonate, $CaCO_3$.

3. Preventive chemical purification is the safest treatment, especially for water used in boilers. It is outside the boiler in containers called purifiers, to which are added chemical reagents that reduce hardness. Various reagents are used, some of which will work only at high temperatures.

The addition of lime, $Ca(OH)_2$, and sodium carbonate, Na_2CO_3, produces this reaction:

$$\begin{aligned}&Ca(HCO_3)_2 + Ca(OH)_2\\ &\quad\rightarrow 2CaCO_3 + 2H_2O; \quad (3)\end{aligned}$$

$$\begin{aligned}&CaSO_4 + Na_2CO_3\\ &\quad\rightarrow Na_2SO_4 + CaCO_3. \quad (4)\end{aligned}$$

The lime causes a reduction of temporary hardness, turning the bicarbonates into carbonates that precipitate. The sodium carbonate reduces permanent hardness, precipitating the calcium of the sulfates. Identical reactions take place for magnesium bicarbonate and magnesium sulfate.

A variation of the process is to add only sodium carbonate in excess. In this case, only the sulfate precipitates in the purifier according to reaction (4). The excess of sodium carbonate enters the boiler and, because of the high temperature, tends to turn into sodium hydroxide:

$$Na_2CO_3 + H_2O \rightarrow CO_2 + 2NaOH, \quad (5)$$

which reacts with the bicarbonate, regenerating sodium carbonate:

$$\begin{aligned}&2NaOH + Ca(HCO_3)_2\\ &\quad\rightarrow CaCO_3 + Na_2CO_3 + 2H_2O. \quad (6)\end{aligned}$$

Water drained from the boiler for the removal of the carbonate precipitates is returned to the purifier so that the excess of sodium carbonate is reused, reducing the consumption of reagent. (This system is used for small, low-pressure boilers because it leads to a heavy formation of CO_2 within the boiler.)

Chemical purification processes employing Na_2CO_3 as a reagent can cause serious problems when used on water for boilers. After a time, the sodium hydroxide, NaOH, formed in the boiler by reaction (5) from the excess of sodium carbonate reacts with the iron of the metal plating to produce a fine film of ferrous-ferric oxide, Fe_3O_4. This film, which would normally prevent any further attack on the iron, breaks easily with the inevitable thermal expansions that occur. The attack on the iron thus continues, especially near areas such as rivets or points. This phenomenon is called caustic weakness, and it causes reduction of the boiler material's resistance to pressures, even to the point of causing breakages. Therefore, sodium carbonate must be used with great caution.

One method of chemical purification that avoids the risk of caustic weakness employs trisodium phosphate, Na_3PO_4, as a reagent. This acts on both temporary and permanent hardness:

$$\begin{aligned}&3Ca(HCO_3)_2 + 2Na_3PO_4\\ &\rightarrow Ca_3(PO_4)_2 + 3Na_2CO_3 + 3CO_2 + 3H_2O; \quad (7)\end{aligned}$$

$$\begin{aligned}&3CaSO_4 + 2Na_3PO_4\\ &\quad\rightarrow Ca_3(PO_4)_2 + 3Na_2SO_4. \quad (8)\end{aligned}$$

This reagent produces virtually complete precipitation of the calcium and magnesium salts as phosphates.

The reaction is promoted if carried out at high temperatures and with a pH of about 10. Sodium phosphate purification is especially appropriate if a large quantity of silicates is present. Because this purification process does not cause caustic attacks on the boiler, it may be used after the lime-soda process to complete the softening of the water.

4. Purification by ion exchange eliminates calcium and magnesium salts from water through the use of substances known as ion exchangers. The first known substances of this type were the zeolites, double-hydrated silicon-aluminates having a crystalline structure with gaps in the crystal network. Such substances are quite common in nature.

Because of the gaps, zeolites acquire and lose water molecules without altering their crystalline structure. When these silicates come into contact with the dilute solution of a calcium and magnesium salt, the latter replace sodium in the crystal network.

Products currently used for this type of purification are all obtained by chemical synthesis or polymerization processes. They consist of small spheres about 0.5 mm (about 0.02 in.) in diameter, and are used as sodium salts or as acids and free bases. In the first case, the resin is in a watery solution that dissociates into the ions composing it:

$$Na_2{-}R \rightarrow 2Na^+ + R^-. \qquad (9)$$

The negative ion (R^-) has a greater chemical affinity for the calcium and magnesium ions (deriving from the dissociation of the relevant salts) than for the sodium ion. Thus, if the resin comes into contact with hard water, a reversible exchange reaction of positive ions (cations) takes place:

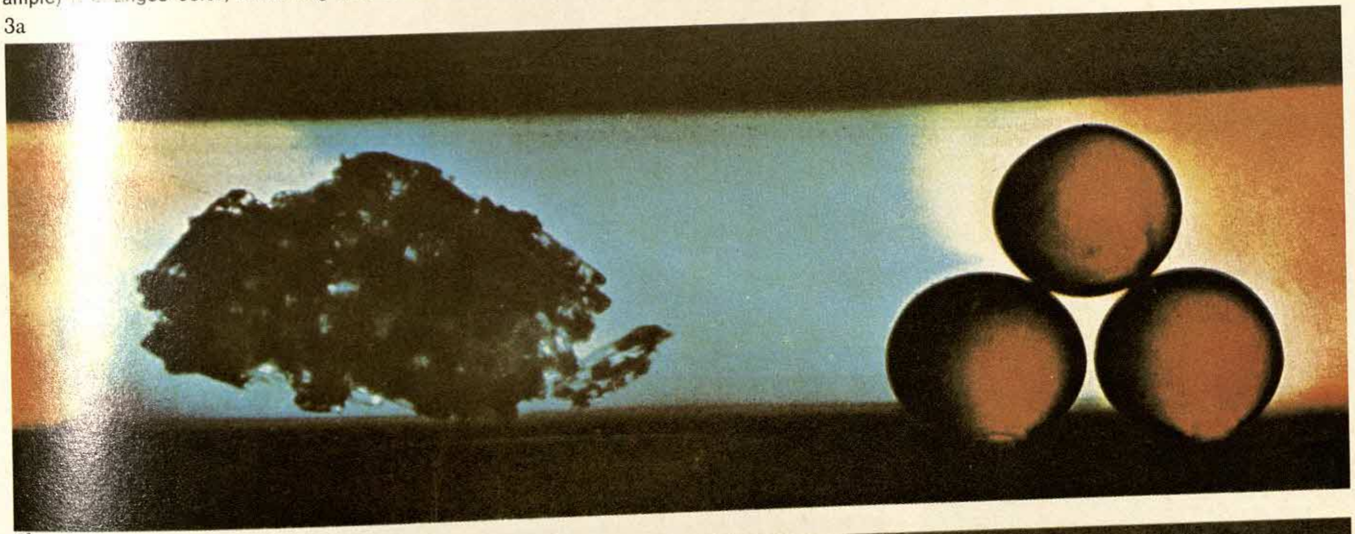
$$Na_2{-}R + CaSO_4 \rightarrow Ca{-}R + Na_2SO_4 \qquad (10)$$

causing the complete elimination of the calcium and magnesium. Reaction (10) takes place when water is passed through a container filled with resin; the water

HOW ION EXCHANGE RESINS WORK—Here are examples of cationic and anionic exchange. In Illustration 3a, a flow of colored water runs from left to right. When it comes into contact with a crystal (trisodium phosphate, for example) it changes color, indicating that a salt has gone into solution in an alkaline reaction. When the water reaches the cation exchange resin, it changes color again because the solution once again becomes acid, while the Na^+ cation sticks to the resin's granules. The same reaction takes place in the case of an anionic resin (Illustration 3b). When a solution containing anions (Cl^-, for example) comes into contact with the resin, the color changes. The reaction is

$$\text{resin}-OH + NaCl \rightarrow \text{resin}-Cl + NaOH.$$

3a



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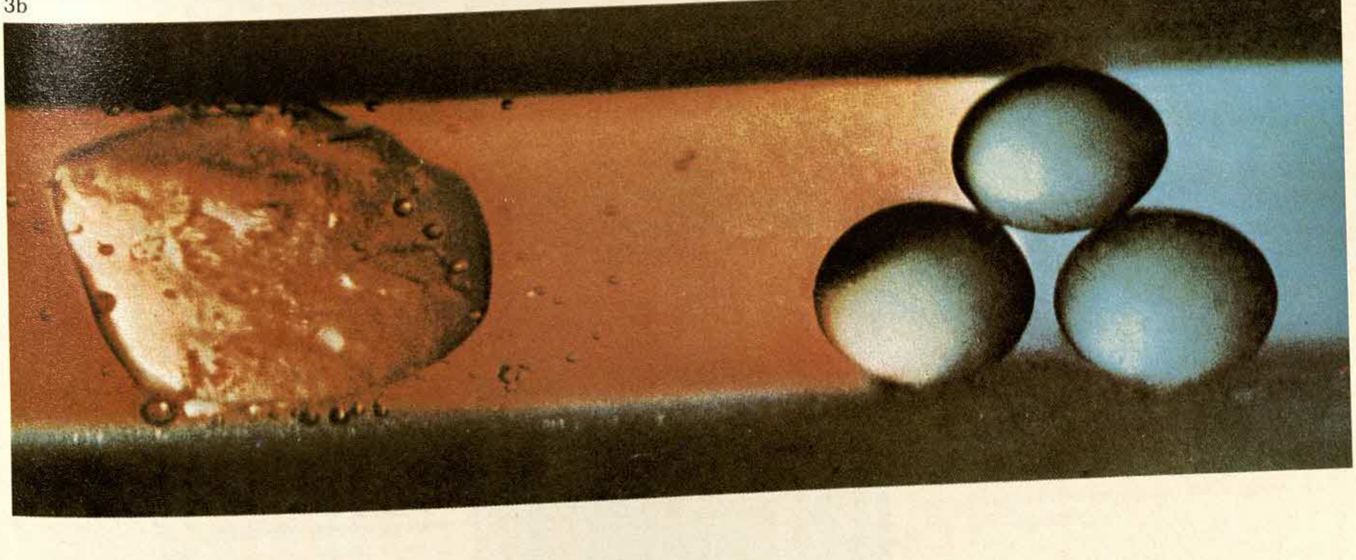
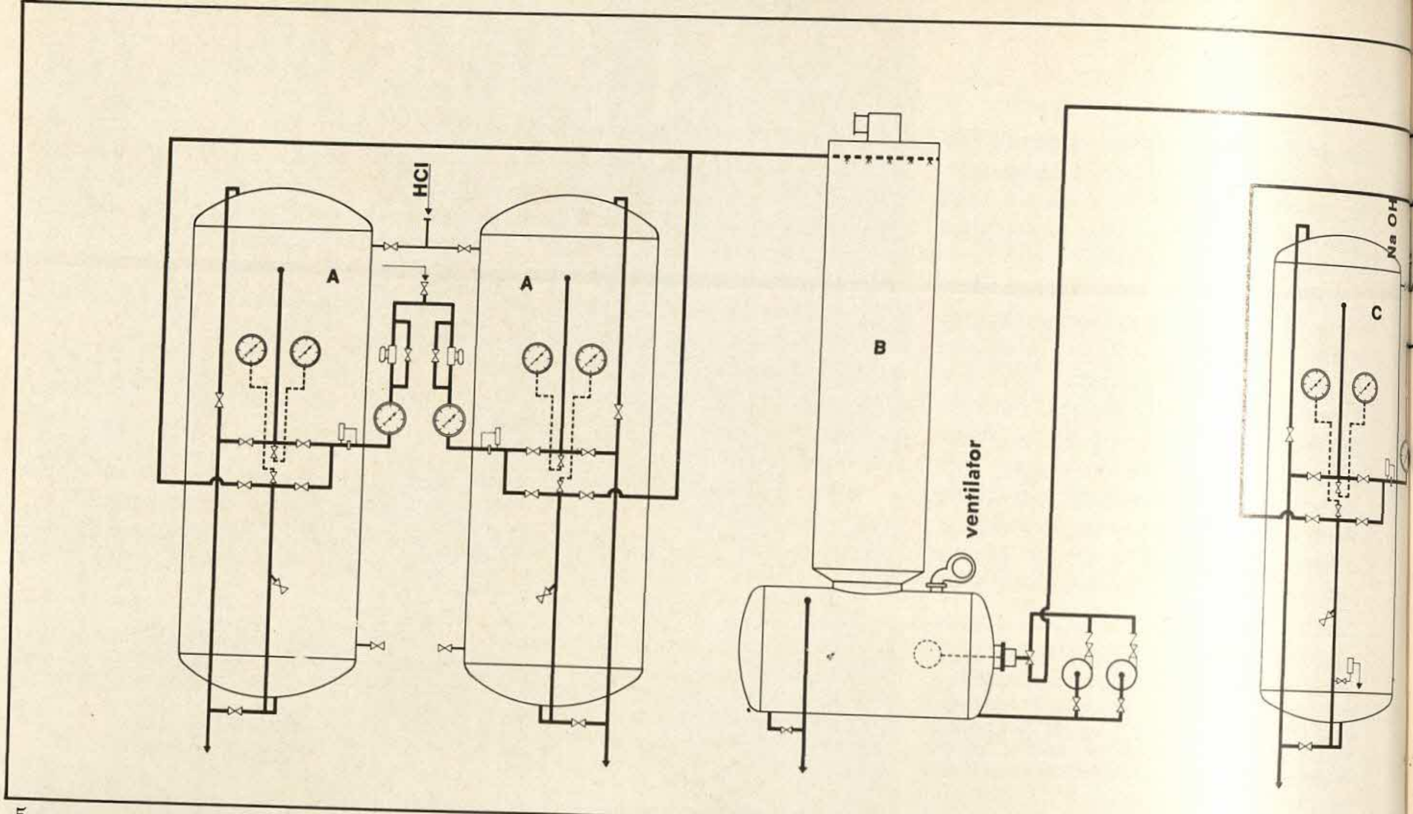




5

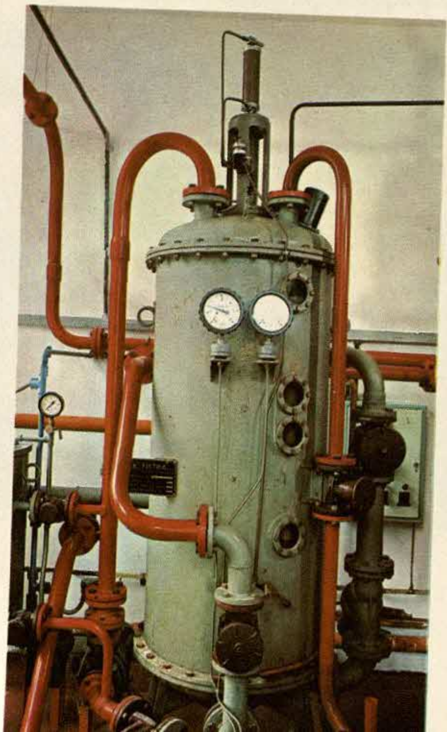
CATION PURIFICATION — These towers are part of the cycle of a purification plant. They perform the first stage—cation purification—which generally involves the use of a particular sulfonic resin.

loses its calcium and magnesium ions and enriches itself with the sodium ions surrendered by the resin.

After the resin has lost its sodium ions, it must be regenerated to reactivate its exchange properties. The flow of water to be purified is stopped, and the resin is bathed with a sodium chloride solution:

FILTRATION PLANT—To obtain water with a higher degree of purity, further filtration can be carried out in a precoat filter. In a purification plant, such a filter tower is usually located before the cationic purifiers.

6



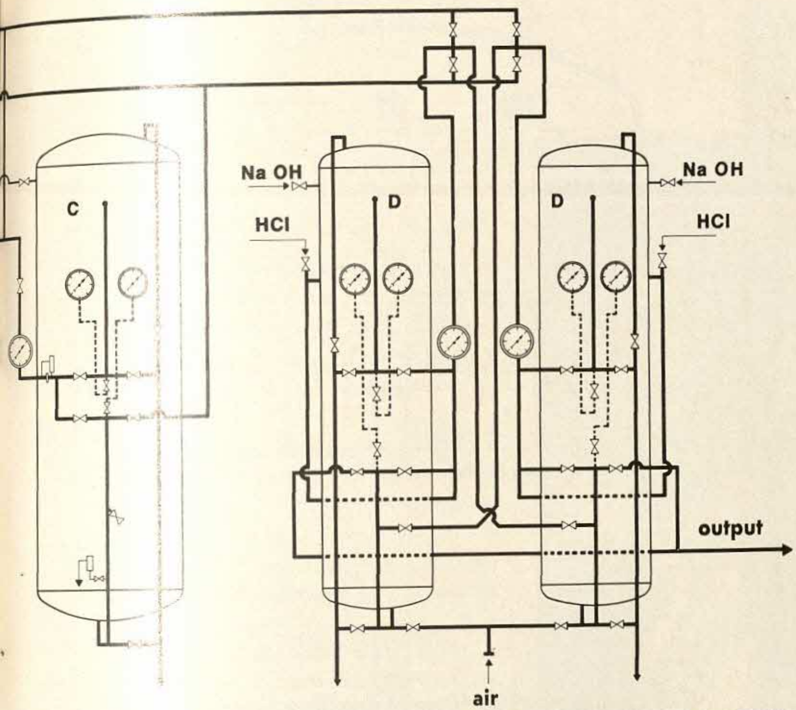
$$Ca{-}R + 2NaCl \rightarrow Na_2{-}R + CaCl_2. \quad (11)$$

With the purifier thus regenerated, a new cycle is begun.

Water treated with resin becomes excessively rich in sodium salts, and may not be suitable for certain industrial uses. More satisfactory results can be obtained by treatment with synthetic resins that may be involved in the exchange of either positive or negative ions. The first hold the cations (Ca^{2+}, Mg^{2+}, Na^{+}, etc.) and the second the anions (SO_4^{2-}, HCO_3^{-}, Cl^{-}, etc.). By exploiting the combined action of the two types of resin, a high degree of purity is obtained.

5. Purification by electrodialysis is one of the most modern purification methods and produces water virtually free of salts. The process is based on the fact that passing an electrical current through a solution causes the migration of ions toward the opposite electrode.

Electrodialysis takes place in a cell with two membranes, one cationic and the other anionic; the membranes divide the cell into three sections. Electrodes are immersed in each of the end sections, and the water to be purified is placed in the central section. The passage of electrical current between the two electrodes causes the migration of ions toward the end zones, leaving pure water in the center section.

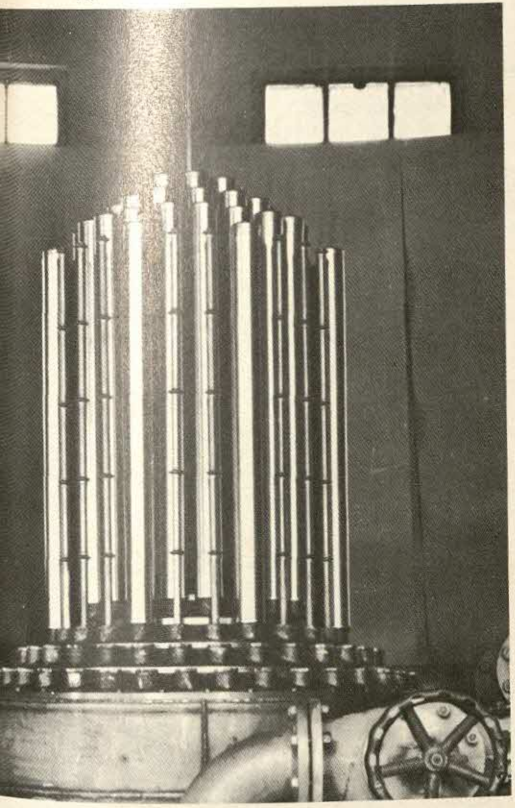


LAYOUT OF A WATER-PURIFICATION PLANT—For most industrial uses, even very careful filtration is not enough to eliminate the impurities in water. Saline content must also be reduced or eliminated to prevent serious problems. This illustration shows the layout of a modern water purification plant.

Prior to filtration, water reaches the cation exchangers **A,** entering from the top through a resin bed (usually polystyrene sulfonic resin) and surrendering its cations. Next it moves to the degassing tower **B,** where gases dissolved in the water—particularly carbon dioxide—are eliminated. In **C** the water undergoes purification by anion exchange resins. These are usually resins containing quaternary ammonium groups, whose strong base gives them strong exchange capacities. Finally, the water passes through exchangers **D** with a mixed bed, made up of both anionic and cationic resins.

After undergoing these demineralization processes, the water is passed through final filtration, or it may be used directly.

7a



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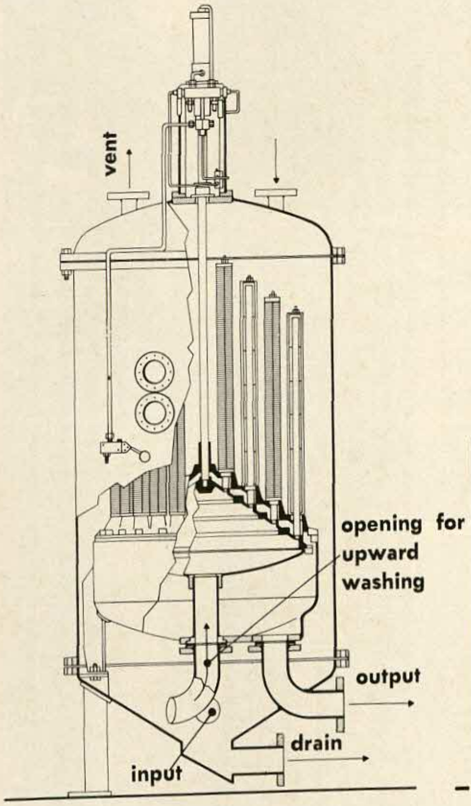
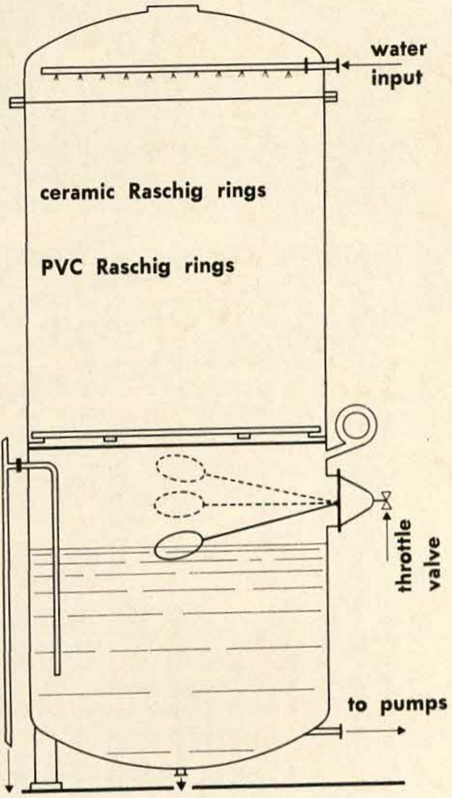


PRECOAT FILTER—Illustration 7a shows the inside of a precoat filter. The stainless steel filtering rods form a spiral on which is deposited a layer of cellulose or fossil flour of micron-sized particles.

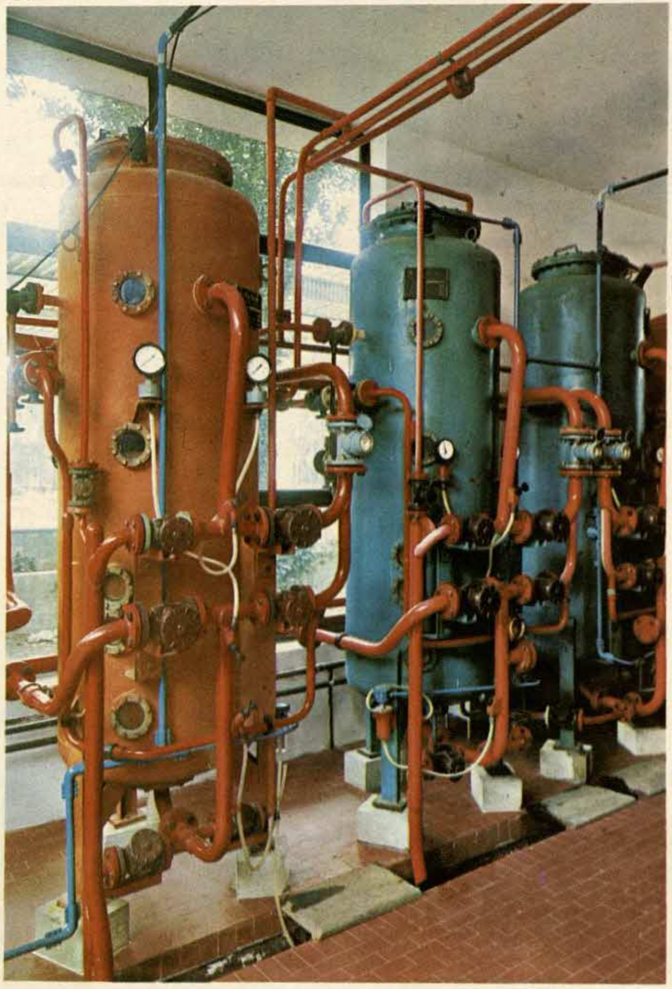
The rods rest on the surface of a cone, within which a like number of steel tubes move vertically (Illustration 7b). This makes it possible to wash the filtering surfaces automatically and effectively with the least possible consumption of water and air.

8

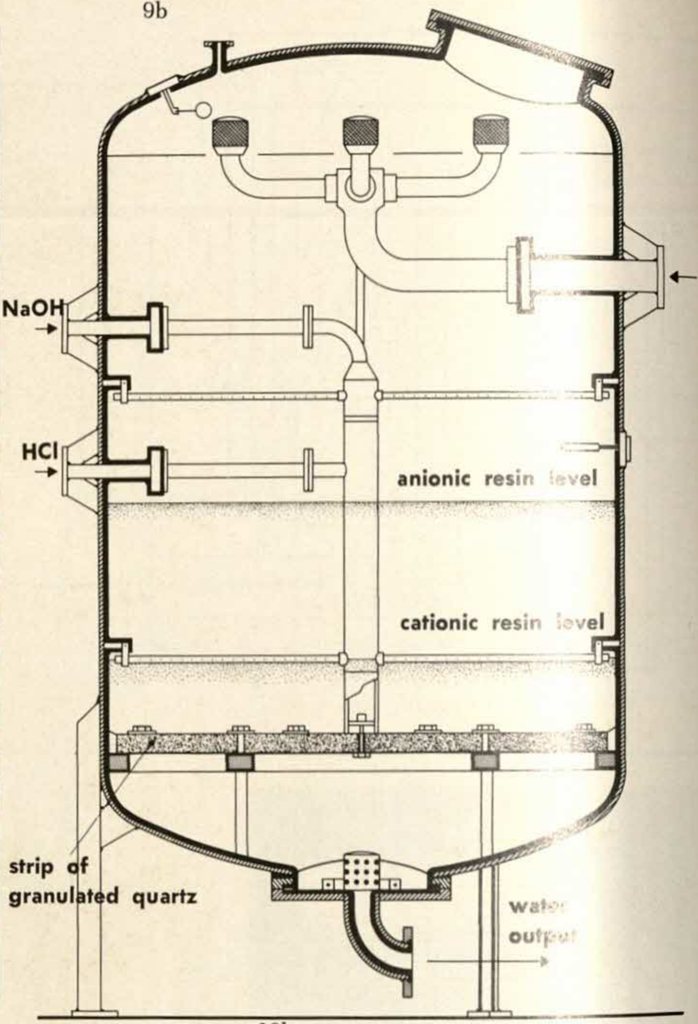


DEGASSING TOWER—Water pours down on a layer of ceramic Raschig rings, then onto a layer of polyvinyl chloride (PVC) rings; the water then meets a flow of air blowing in the opposite direction. In the lower part of the tower is a reservoir, with a ballcock attached to a throttle valve regulating the influx of water into the degasser.

9a



9b



MIXED-BED EXCHANGERS—Illustration 9a shows towers containing a mixture of cation and anion exchange resins; Illustration 9b shows the layout of these exchangers. In the regeneration phase, the two resins, which form a perfect mixture, must be separated. This is done by exploiting the weight difference between the particles of the resins, which thus form layers. The anionic resin of the upper layer is regenerated by a rain of NaOH, which completely exhausts the lower cationic layer. The latter is then regenerated by HCl solution, distributed at the level of the anionic resin.

After regeneration is completed, the two resins are mixed again by a jet of air.

THE CONDUCTIVITY OF WATER—At the foot of anionic and mixed-bed purifiers, a check is made on the water's conductivity to see if purification has reached an optimum level. Illustration 10a shows a plant's control panel. A chart in the center of the panel registers the water's conductivity curve, allowing a continuous check. The cell shown in Illustration 10b measures the conductivity of the purified water.

10a

10b

The degassing of water is a stage of purification that is very important to prevent the negative effects of dissolved gases, especially in water used in boilers. This can be done by heating or by vacuum.

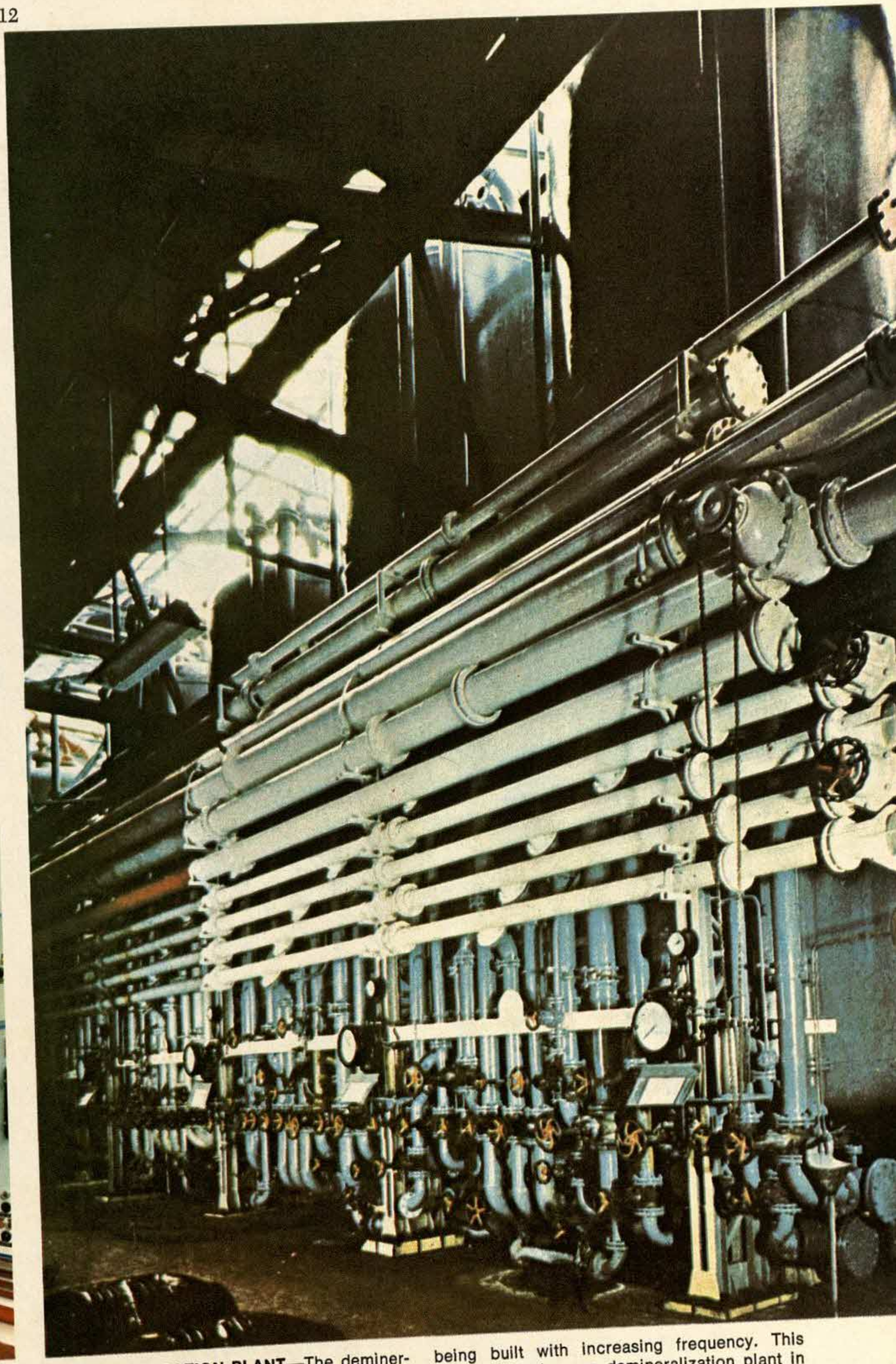
Steam degassing is based on the first principle. Water is sprayed into a cylindrical container from above; steam is introduced from below. The steam meets the water and diminishes the solubility of the gases dissolved in it, enabling them to separate off.

In vacuum degassing, the water is passed through a container in which a strong vacuum is maintained by a system of ejectors that reduces the gases' solubility and extracts them as they are freed.

REGENERATION OF CATIONIC AND ANIONIC RESINS—These tanks contain the hydrochloric acid and sodium hydroxide that regenerate the resins. Solutions sent to the towers containing cationic and anionic resins percolate through the tanks to eliminate all cation and anion traces.

11

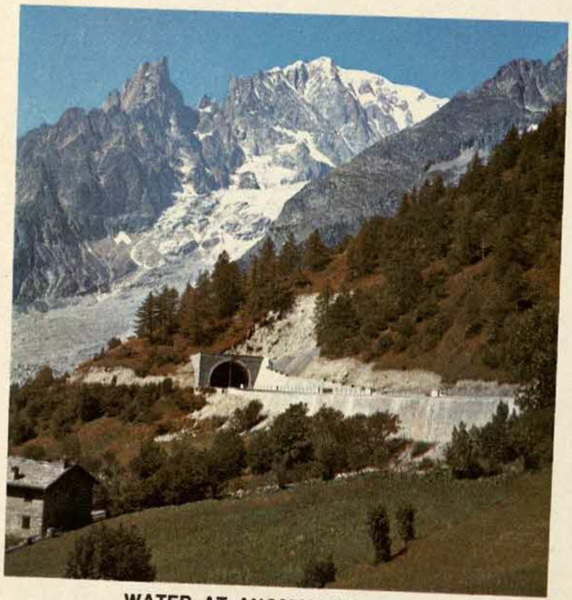
12



A DEMINERALIZATION PLANT—The demineralization of water is very important to industry, and complex installations for this purpose are being built with increasing frequency. This photograph shows a demineralization plant in a large German factory.

GROUNDWATER | artesian wells and hot springs

1



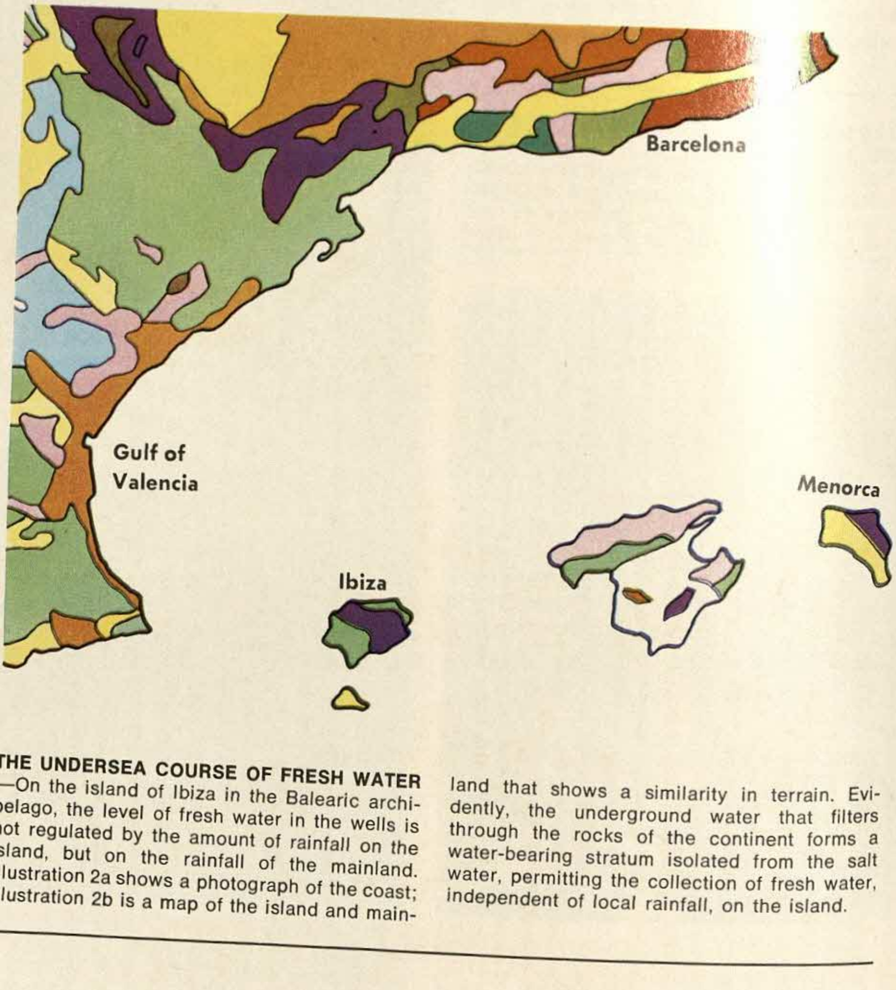
WATER AT ANOMALOUS TEMPERATURES—The highway tunnel that unites Italy with France is about 10.5 km (about 6.5 mi) long and passes under the massif of Mount Blanc. The tunnel is more than 2,000 m (about 6,500 ft) deep. During its excavation, about midway through the tunnel, a water vein was struck. The temperature of the water was much lower than the rocks from which it appeared. This means that the water was cooled additionally by an infiltration of the ice forming an almost continual mantle over the rocks.

A study of groundwater includes both an analysis of its characteristics, in order to trace its deep origins, and an examination of the geological terrain at the point of issue—an examination that leads to an explanation of how the water can rise at a point far from its source.

Two characteristics of water originating from depths are abundance and steadiness of flow. These are independent of seasonal changes in rainfall. Water that comes out of the Earth after having followed a long underground course usually has a constant flow at its points of issue, because all the terrain it has crossed before rising to the surface makes up a kind of large reservoir that levels out variations caused by rainfall.

2a

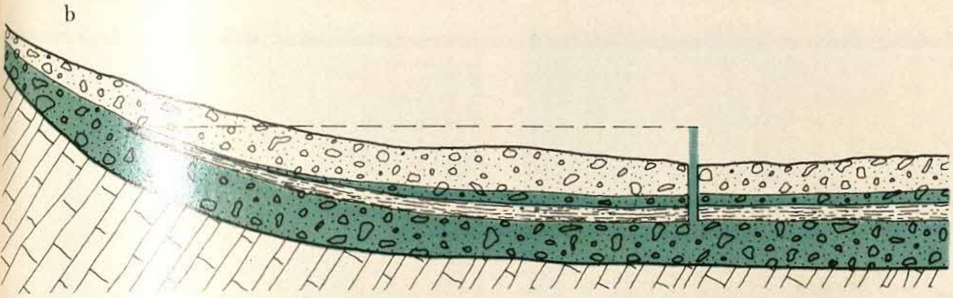
2b



THE UNDERSEA COURSE OF FRESH WATER—On the island of Ibiza in the Balearic archipelago, the level of fresh water in the wells is not regulated by the amount of rainfall on the island, but on the rainfall of the mainland. Illustration 2a shows a photograph of the coast; Illustration 2b is a map of the island and mainland that shows a similarity in terrain. Evidently, the underground water that filters through the rocks of the continent forms a water-bearing stratum isolated from the salt water, permitting the collection of fresh water, independent of local rainfall, on the island.

3

b



ARTESIAN WELLS—When an artesian well is tapped, the water occasionally surges up under pressure and gushes above ground level (Illustration 3a). Illustration 3b shows the terrain in which an artesian stratum has formed. The well water does not spurt up to the same height as the entrapped point of the stratum because the water in the artesian stratum loses pressure, both in rising up to the well and along its underground course, due to the capillary conductivity of the ground.

a

Groundwater most often accumulates far from its point of issue. Often, water suddenly appears in wadis even when there has been no local rainfall, the increased flow resulting from a distant rainfall. Another example is the hydrogeology of the Po plains in Italy. Here, a large amount of water comes from the southern slopes of the Alps. A well dug in the plain produces water that obviously comes from a distant place.

Temperature is another important feature of groundwater. The temperature of water at its point of issue may be easily measured by a chemical thermometer. The temperature is often a clue to what has happened to the water on its way to the surface.

The deeper the origins of groundwater springs, the more constant are their temperatures, because the seasonal influences of the temperature of a region are increasingly less intense at great depths. For example, at 50 m (about 160 ft) under any terrain the seasonal variations of temperature have little effect. Groundwater usually has the same temperature as the rock layers in which it rests for the longest period.

Consider the temperature changes that occur during the day, at night, and with each season. When the water-bearing stratum of the land is under a thin layer of permeable land (for example, on the slope of a glacial valley barely covered with loose soil), it reacts notably to outside temperature variations. In fact, during the summer when the sun beats down on the valley, a thermal wave can reach the rocky layer and heat the water-bearing stratum. During the winter, the spring may even freeze, a definite indication of the shallow origin of the water itself.

Even one measurement of the temperature of the issuing water can be useful if taken at the right moment. Hot water (6 to 12° C or about 43 to 54° F) in winter or cold water (10 to 15° or about 50 to 59° F) in summer indicates the deep origins of the water and its surroundings. The temperature of the hot water is lower than that of the so-called cold water, which shows the relationship with the seasonal temperatures.

An easy but important observation that can be made with an inexpensive thermometer is determining the temperatures of neighboring springs. By comparing temperatures, it is possible to deduce whether the springs have the same source or are independent. Springs with similar temperatures, which are constant and independent of atmospheric fluctuations, often have the same place of origin because the waters have followed the same course.

In order to discover the origins of a spring along the lower part of a mountain valley, its temperature must be determined, its flow examined, and its relationship with the environment considered. The temperature can then be compared with temperatures of nearby springs in the same position between the slopes and the valley bed. If any similarities in these temperatures exist, it should be fairly easy to correlate them and trace their origins by examining the surrounding geological features for rocky banks and fractures.

Another feature of groundwater that makes it possible to trace its origins is its steady flow. By digging a small, divided, inclined channel it is possible to see the level that the water reaches. This is not a precise observation but gives a rough idea of the flow and makes it possible to compare the flow with others at different times. After making a first observation in summer, another can be made in winter. If the water source is superficial, the ice will diminish or even block its flow. (If the land is dry in summer, in the winter there may be an increase in

4

a

b

MINERAL WATER—Water that follows a deep underground course is often mineralized. A common mineralization is that of gas. The spring in Illustration 4a contains carbon dioxide. Other water may be sulfuric. The spring shown in Illustration 4b is in the Syrian desert. It is cool, constant-flowing, and abundant, which indicates that it comes from deep sources. Unsurprisingly, it is sulfurous.

the flow.) These observations must be made in the same spot at six-month intervals.

Other interesting observations can be made in one season. For example, in summer, the flow can be observed before and after a storm. If there is an increase in the flow of water, then it is surface water. Even groundwater can show such variations, but these follow their climatic origins and are sometimes retarded by months.

Another important observation concerns turbidity of the water. Usually, the primary source of water is rain or melting snow. Rainwater has a strong solvent power and, therefore, an analysis of what it contains in solution may indicate its underground course. The analysis should be correlated with geological observations of the region because groundwater is usually completely free of mud. A precise analysis of the sediment is rather difficult. A careful examination of the sediment may be sufficient. A sample of the water should be left in a transparent container until the sediment settles. Then the sediment can be collected and examined to see if it contains inorganic substances or humus (in the latter case, the water will not be potable because it is surface water). A simple, but refined, analysis consists of ascertaining the difference in weight between the dry sediment and the calcined sediment. (Organic substances produce a great difference in weight.)

Great numbers of minor and trace elements, including radioactive constituents, have been found in groundwater. Two general types of natural radioactive components may be present. The first type is related to ancient radioactive material that probably was present when the Earth was formed. Examples are thorium, uranium, radioactive potassium, and their products of disintegration, such as radon and radium. Concentrations of uranium and radioactive potassium seldom exceed one part per million of dissolved solids in natural waters. Because of the slow disintegration rates of thorium, potassium, and uranium, they do not produce radiation hazards in natural waters. Radium, however, has a relatively rapid disintegration rate; furthermore, it tends to accumulate permanently in the bones of vertebrates. As a consequence, radium is the most hazardous inorganic material known to be carried in water. Fortunately, even minute concentrations are rarely found in normal groundwater.

The second type of natural radioactive materials found in groundwater originates in cosmic radiation of the atmosphere and the Earth's surface. Radioactive hydrogen (H^3 or tritium) and carbon (C^{14}) are the two most important products from the standpoint of groundwater studies. Because they are produced only at the surface, relatively large concentrations indicate that the groundwater originated at the surface in the recent past. Tritium disintegrates so rapidly that it is used to obtain approximate dates in terms of a few decades. Carbon-14, which disintegrates more slowly, is useful for dating back several thousand years. Neither tritium nor carbon-14 is a health hazard when in natural concentrations in groundwater.

In the case of water found in plains or taken from wells, its pressure indicates the depth from which it springs and the type of basin in which it collected before surfacing. In a well, the depth at which the water collects indicates the level of the water-bearing stratum. If the water gushes out in spurts, an artesian stratum has been struck.

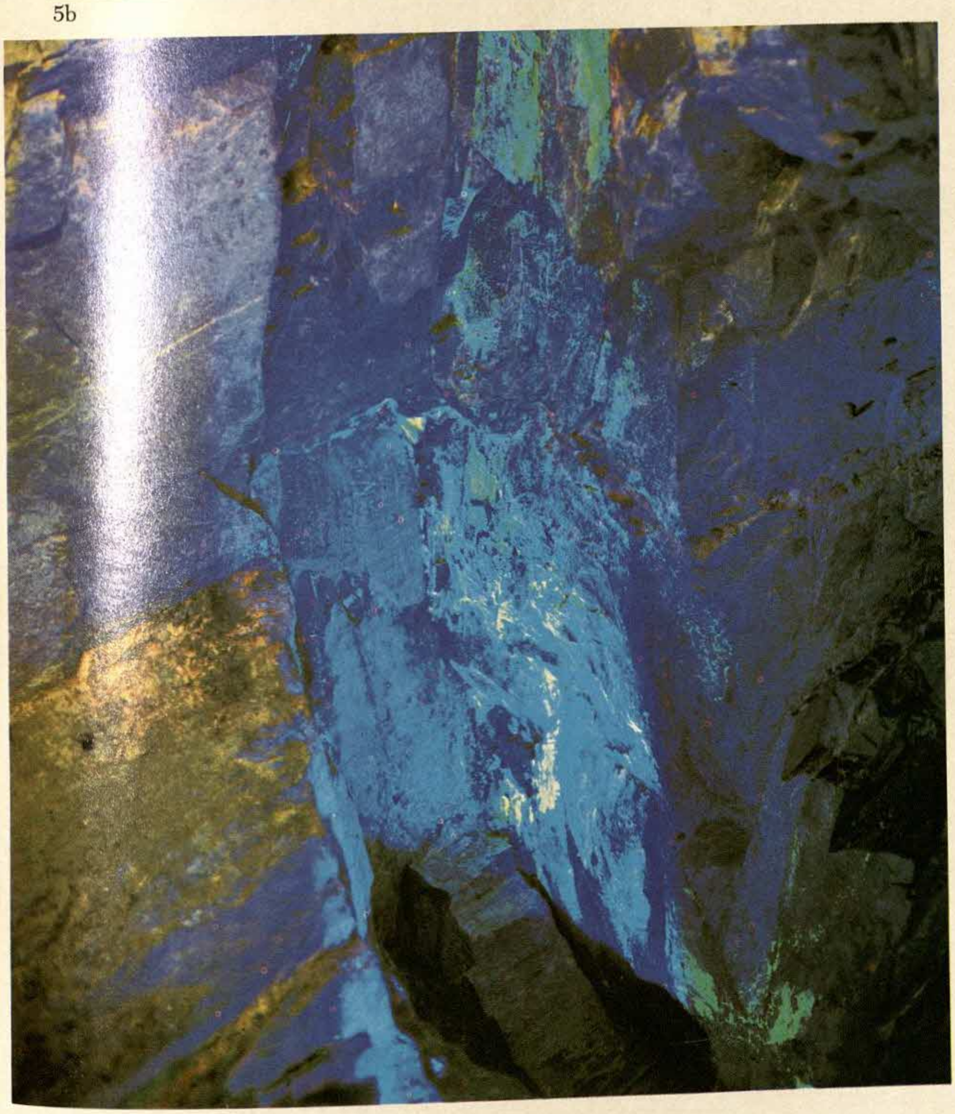
It is not difficult to detect certain things about water that indicate its underground course has reached great depths. Water that comes up from 2,000 m (about 6,500 ft) under a mountain is considered to be deep even if at this height the water is well above sea level.

Another characteristic of very deep water is that its temperature, in addition to being constant, is higher than the 11° C (about 51° F) temperature of the rocks near the surface (below the region subject to climatic changes). The greater the depth, the higher the temperature. The water may become heated even if it does not travel through volcanic zones.

Deep thermal waters present a wide range of characteristics such as the presence of carbon dioxide dissolved in the water. If this water is collected in a bottle that is kept at the same temperature as the water at its issue and then heated by 10 to 15° C, gas is liberated. This is the gas that was not liberated at the point of issue.

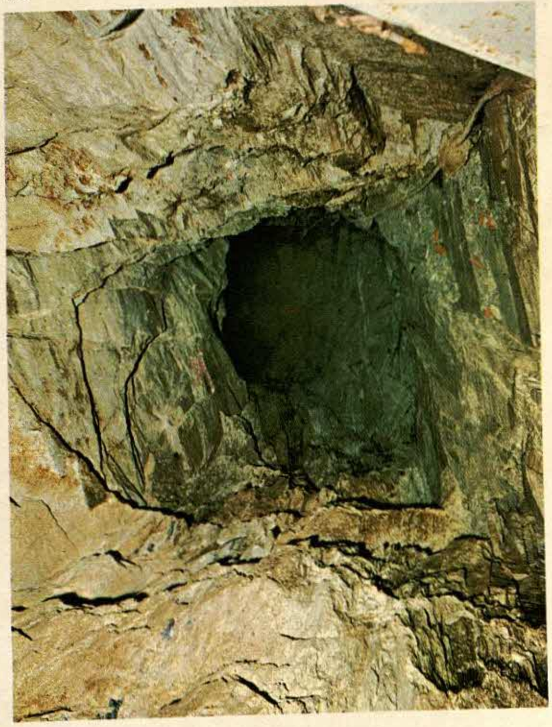
A hot spring often makes interesting deposits along the channels that carry it to the surface. These deposits vary according to the matter that the water dissolves during its course and the decrease in temperature that it undergoes traveling through the various natural underground channels.

5b



MINERAL DEPOSITS IN GROUNDWATER — The Lurisia spring (Illustration 5a) is one of the most radioactive in Italy. Other radioactive springs are on the island of Ischia and the Pliniana of Bormio (Sondrio). The water from these springs passes through long crystalline schists of uranium and, therefore, contains radioactive salts in solution. The mineralization that occurs due to the deposits by the water when it rises to the surface can be seen under ultraviolet light (Illustration 5b). The water shows fluorescent reflections caused by the uranium. Such a form of mineralization is a curiosity; the entire zone through which the water passes is a uranium deposit.

5a



ABBREVIATIONS

A	ampere
Å	Ångstrom unit
abs	absolute
a-c	alternating current (as an adjective)
amu	atomic mass unit
atm	atmosphere
at. wt	atomic weight
AU	astronomical unit
avdp	avoirdupois
Bev	one billion electron volts
bhp	brake horsepower
bhp-hr	brake horsepower-hour
bp	boiling point
Btu	British thermal unit
C	temperature Celsius; temperature Centigrade
c	candle
cal	calorie
cfm	cubic feet per minute
cfs	cubic feet per second
cgs	centimeter-gram-second (system)
cl	centiliter
cm	centimeter
cm^2	square centimeter
cm^3	cubic centimeter
coef	coefficient
colog	cologarithm
cos	cosine
cot	cotangent
cp	candlepower
csc	cosecant
cu	cubic
cu ft	cubic foot
db	decibel
d-c	direct current (as an adjective)
doz	dozen
E	electromotive force
e	the base of the system of natural logarithms
ev	electron volt
F	temperature Fahrenheit
fp	freezing point
fpm	feet per minute
fps	feet per second
ft	foot; feet
ft^2	square foot
ft^3	cubic foot
ft-c	footcandle
ft-lb	foot-pound
G	universal gravitational constant
g	gram
gal	gallon
g-cal	gram-calorie
gpm	gallons per minute
gps	gallons per second
hr	hour
$h\nu$	photon energy
hp	horsepower
Hz	hertz (cycles per second)
I	electric current
ID	inside diameter
in.	inch
$in.^2$	square inch
$in.^3$	cubic inch
in.-lb	inch-pound
ips	inches per second
j	joule
K	temperature Kelvin (absolute)
kcal	kilocalorie
kg	kilogram
kg-cal	kilogram-calorie
kg-m	kilogram-meter
kg/m^3	kilograms per cubic meter
kgps	kilograms per second
km	kilometer
kv	kilovolt
kw	kilowatt
kwhr	kilowatt-hour
l	liter; lumen
lat	latitude
lb	pound
lb-ft	pound-foot
lb/ft^2	pounds per square foot
lb/ft^3	pounds per cubic foot
lb-in.	pound-inch
l-hr	lumen-hour
lin ft	linear foot
log	logarithm (common)
$\log_e$	logarithm (natural)
long.	longitude
m	meter; minute (time, in astronomical circles)
m^2	square meter
m^3	cubic meter
ma	milliampere
Mev	one million electron volts
mg	milligram
mh	millihenry
mi	mile
mi^2	square mile
min	minute
m-kg	meter-kilogram
ml	milliliter
mm	millimeter
mm^2	square millimeter
mm^3	cubic millimeter
$m\mu$	millimicron
mph	miles per hour
mphps	miles per hour per second
mv	millivolt
N	Avogadro's constant
$n!$	factorial *n*
OD	outside diameter
oz	ounce
pH	rating on acid-alkaline scale
ppm	parts per million
psi	pounds per square inch
psia	pounds per square inch absolute
R	temperature Reaumur; resistance
RA	right ascension
rpm	revolutions per minute
rps	revolutions per second
sec	secant; second
sin	sine
sp gr	specific gravity
sq	square
tan	tangent
V	volt
VA	volt-ampere
W	watt; work
yd	yard
yd^2	square yard
yd^3	cubic yard

SCIENTIFIC SYMBOLS AND ABBREVIATIONS

α	alpha particle
β; β^-	beta particle
β^+	positron
γ	gamma radiation
Δ	a small change; heat
λ	wavelength; radioactive-decay constant
ma	milliampere
μc	microcurie
μf	microfarad
μin.	microinch
μm	micron
$\mu\mu$	micromicron
$\mu\mu$f	micromicrofarad
ν	frequency; neutrino
π	3.14159; osmotic pressure
Σ	the sum of
σ	nuclear cross section (barns); area
Ω	electrical resistance (ohms)
ω	angular speed; angular velocity
′	minute (angular measure)
″	second (angular measure)
♂	male
♀	female
>	is greater than
<	is less than
∝	is proportional to
∞	infinity
√‾	square root of
°	degrees; temperature; angle measurement (example, 30°)
[ ]	molar concentration
+	positive electric charge; mixed with; plus
—	negative electric charge; single covalent bond; minus
=	equals; double covalent bond; produces
≠	does not equal
≡	triple covalent bond
→	produces; forms; chemical reaction
⇄	reversible chemical reaction
↑	gas produced by a chemical reaction
↓	precipitate produced by a chemical reaction
*	radioactive substance (follows symbol of element; example, Cl^*)

THE ILLUSTRATED SCIENCE DICTIONARY

Downhill Orbit to Equator

KEY TO PRONUNCIATION

The diacritical marks are:

ə	b*a*nan*a*, *a*but
ᵊ	preceding l, m, n as in batt*le*
ə̇	*e*lectric
ər	f*ur*ther
a	m*a*t
ā	d*ay*
ä	c*o*t, f*a*ther
au̇	n*ow*, *ou*t
e	b*e*t
ē	b*ea*t
i	t*i*p
ī	b*i*te
j	*j*ob, *g*em
ŋ	si*ng*
ō	b*o*ne
ȯ	s*aw*, *a*ll
ȯi	c*oi*n
th	*th*in
t͟h	*th*en
ü	r*u*le, f*oo*l
u̇	p*u*ll, w*oo*d
ue	German h*ü*bsch
u̅e̅	French r*ue*
yü	*u*nion
zh	vi*si*on

ˈ mark preceding the syllable with strongest stress.
ˌ mark preceding a syllable with secondary stress.

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downhill orbit \\'daủn-ˌhil 'ȯr-bət\\

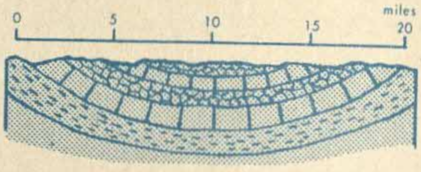
ASTRONAUTICS. That part of a satellite's orbit that carries the satellite closer to the body around which it is orbiting; see also *uphill orbit.*

A satellite in orbit around the sun has its speed increased by the sun's gravity during its DOWNHILL ORBIT.

downwarp \\'daủn-ˌwȯ(ə)rp\\ *n.*

EARTH SCIENCE. A wide, shallow fold on the earth's surface created by rock beds dipping inward toward a central area; also, a broad area where the rock beds are bent downward.

The heavy load of a continental glacier can cause a DOWNWARP *in the crust of the earth.*



DOWNWARP

Dow process \\'daủ 'präs-ˌes\\

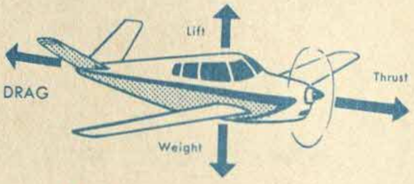
CHEMISTRY. A method of producing magnesium metal by the electrolysis of molten magnesium chloride.

The magnesium chloride used in the DOW PROCESS *is obtained from seawater.*

drag \\'drag\\ *n.*

AERONAUTICS and ENGINEERING. The retarding force acting on a body, such as an airplane, that is in motion through a fluid, such as air. Drag is parallel and opposite to the direction of the body's motion.

Streamlining an airplane reduces DRAG.

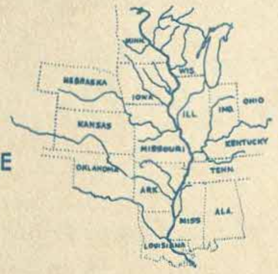


DRAG

drainage \\'drā-nij\\ *n.*

EARTH SCIENCE. The manner in which surface water drains away by flowing down to rivers and streams; also, the streams, rivers and waterways by which an area is drained; also, the water that flows off; also, the region or area that is drained.

The Mississippi River provides DRAINAGE *for many states.*



DRAINAGE

dram \\'dram\\ *n.*

MEDICINE. A unit of weight equal to 60 grains (used by pharmacists); also, a unit of avoirdupois weight equal to 27.343 grains, or 1⁄16 of an ounce.

The metric equavalent of one DRAM *is 3.887 grams.*

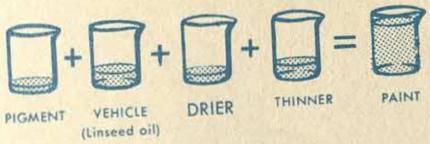
Draper classification \\'drā-pər ˌklas-ə-fə-'kā-shən\\

ASTRONOMY. A system of star classification based on the observed lines in star spectra. The system also indicates the color and temperature of a star. The common star types or classes are represented by the letters O, B, A, F, G, K and M.

According to the DRAPER CLASSIFICATION, *G stars, such as the sun and Capella, appear yellow and have surface temperatures of approximately 5,500° K.*

dregs \'dregz\ *n.*
CHEMISTRY. The particles or bits of solid matter that settle to the bottom of a liquid.

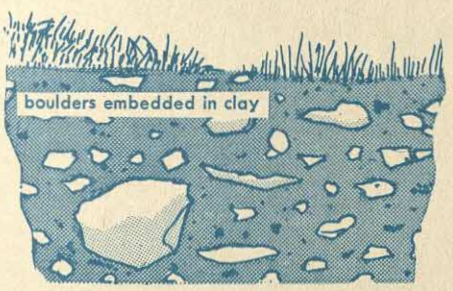
DREGS *may be separated from a liquid by filtration.*



DRIER

drier \'drī(-ə)r\ *n.*
1. CHEMISTRY. A chemical that when added to certain oils, promotes oxidation of the oils to form a tough film. It is usually a compound of cobalt, lead or manganese. 2. ENGINEERING. A piece of equipment used to speed the evaporation of water from a substance.

When a small amount of cobalt chloride is added to linseed oil as a DRIER, *only about four hours are required for the linseed oil to form a tough film rather than the usual three days.*



DRIFT

drift \'drift\ *n.*
1. EARTH SCIENCE. An accumulation of such materials as boulders, gravel, sand and clay that has been carried by the action of glaciers and deposited by the melting ice or meltwater from the ice; also, a pile of snow or sand made by wind or water; also, the motion of floating objects caused by currents in a body of water. 2. AERONAUTICS. The difference between the direction an aircraft is headed and its flight path over the ground. Aircraft drift is usually caused by cross winds. 3. ENGINEERING. A horizontal tunnel connecting two larger tunnels, or a tunnel parallel to an ore vein or layer of rock; also, the tendency of an electric meter to give an inconstant reading.

DRIFT *that has been deposited directly by melting ice is called till.*

driftless area \'drift-ləs 'ar-ē-ə\
EARTH SCIENCE. A region having no glacial drift and apparently never covered by glacial ice even though the surrounding area was glaciated; specifically, the Driftless Area in southwestern Wisconsin.

Glacial deposits around a DRIFTLESS AREA *may represent several periods of glaciation rather than only one glaciation that surrounded the area.*

dripstone \ˈdrip-ˌstōn\ *n.*

EARTH SCIENCE. Calcium carbonate that has been deposited from dripping water in the form of stalactites (rock "icicles" from the ceiling) and stalagmites (rock "icicles" from the floor).

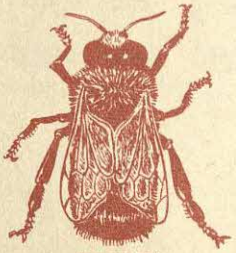
DRIPSTONE *occurs in limestone caverns, such as Mammoth Cave in Kentucky.*

DRIPSTONE

drone \ˈdrōn\ *n.*

1. ZOOLOGY. A male bee. 2. AERONAUTICS. An airplane or other craft remotely controlled by radio.

A DRONE, *while larger than a worker bee, is smaller than a queen bee.*



DRONE

drought \ˈdrau̇t\ *n.*

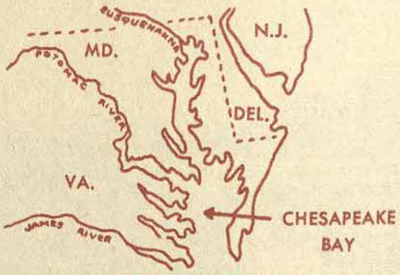
EARTH SCIENCE. A long period of time without rain or other precipitation; also spelled drouth.

Many desert areas of the Southwest now grow vegetable crops throughout the year because irrigation systems provide water during a DROUGHT.

drowned valley \ˈdrau̇nd ˈval-ē\

EARTH SCIENCE. A valley whose lower portions have been covered by sea or lake water due either to sinking land or a rising water level.

Chesapeake Bay, on the eastern coast of the United States, is in a DROWNED VALLEY.



DROWNED VALLEY

drug \ˈdrəg\ *n.*

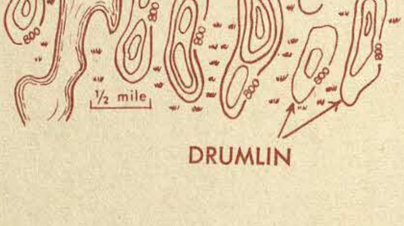
MEDICINE. Any chemical compound or noninfectious biological material used as an aid in the diagnosis, treatment or prevention of a disease; also, a compound used to relieve pain or suffering.

Penicillin is an antibiotic DRUG.

drumlin \ˈdrəm-lən\ *n.*

EARTH SCIENCE. A long, oval hill or ridge formed of glacial drift and shaped by a former ice sheet. Drumlins often occur in groups.

A DRUMLIN *indicates the direction of glacial movement, since its long axis is parallel to the movement.*

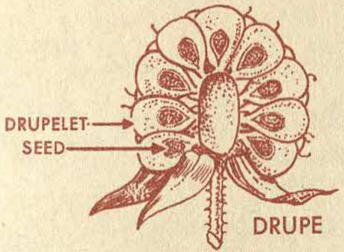


DRUMLIN

drupe \ˈdrüp\ *n.*

BOTANY. A simple fruit, such as a peach, olive or cherry, with an outer skin and a soft, fleshy layer covering a shell, or stone, that contains a single seed.

The seed within a DRUPE *is often carried away from the parent plant by an animal that has eaten the drupe.*



DRUPE

RASPBERRY

dry-bulb temperature \'drī-ˌbəlb 'tem-pər-ˌchu̇(ə)r\
Temperature as measured with an ordinary thermometer; in particular, one of the two temperatures shown by a psychrometer for determining relative humidity; see *wet-bulb temperature, hygrometer* and *psychrometer.*

DRY-BULB TEMPERATURE *is always greater than wet-bulb temperature.*

dry cell \'drī 'sel\
CHEMISTRY and PHYSICS. An electric cell in which the electrolyte ammonium chloride is mixed with other ingredients to form a damp paste.

While a single DRY CELL *produces a relatively-small current at a low voltage, several cells connected in series make a higher-voltage battery.*

FLASHLIGHT BATTERY

DRY CELL

dry-fuel rocket \'drī-ˌf(y)ü(-ə)l 'räk-ət\
ASTRONAUTICS. A rocket that uses a solid propellant.

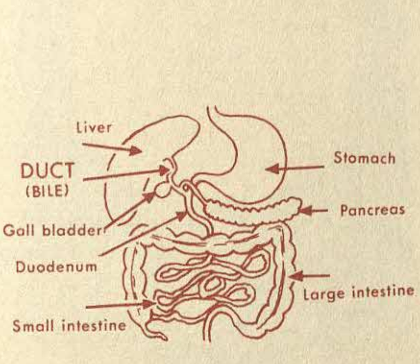
One kind of DRY-FUEL ROCKET *was powered by gunpowder.*

dry ice \'drī 'īs\
CHEMISTRY. A solid form of carbon dioxide, CO_2, having a temperature of −78° C. (−103° F.) or less. Dry ice changes directly from a solid to a gas at warmer temperatures and is useful as a refrigerant, especially for foods in transit.

DRY ICE *has been used for experimental cloud seeding to induce rain.*

dry measure \'drī 'mezh-ər\
MATHEMATICS. A set of units, as bushel, peck, quart and pint, for measuring grains, fruits and other dry products.

A bushel in DRY MEASURE *is equal to four pecks.*



DUCT

duct \'dəkt\ *n.*
1. ANATOMY and ZOOLOGY. A tube or canal that carries away secretions or excretions, particularly from glands. 2. BOTANY. A tube formed by a row of elongated cells that have lost their intervening end walls. 3. ENGINEERING. A tube used in a heating, ventilating or exhaust system; also, a pipe, often underground, for electric cables or telephone lines.

Accumulations of crystalized fat particles in a bile DUCT *sometimes result in the formation of gallstones.*

ductility \ˌdək-'til-ət-ē\ *n.*

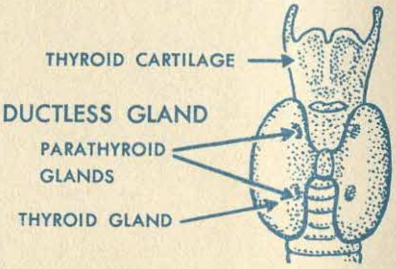
PHYSICS. The property of a substance that allows it to be pulled out into thin threads or wires without breaking. It is a characteristic typical of many metals, such as copper and aluminum.

Glass, when softened by heat, has high DUCTILITY.

ductless gland \'dəkt-ˌləs 'gland\

ANATOMY and ZOOLOGY. A gland that produces hormones that are released directly into the bloodstream instead of through a duct; see *endocrine gland.*

Doctors sometimes prescribe synthetically-prepared hormones for a patient with a defective DUCTLESS GLAND.



dune \'d(y)ün\ *n.*

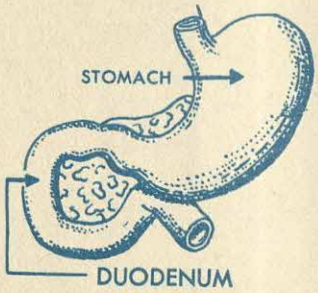
EARTH SCIENCE. A mound, hill or ridge of sand formed by the wind, usually located on deserts or along sea or lake shores.

When the prevailing wind blows primarily from one direction, a sand DUNE *may move from 25 to 50 feet in one year.*

duodecimal system \ˌd(y)ü-ə-'des-ə-məl 'sis-təm\

MATHEMATICS. A system of numeration having a base of 12 instead of 10 as in the decimal system.

In the DUODECIMAL SYSTEM, *16 represents one unit of 12 plus six units of ones so that 16 in this system is equivalent to 18 in the decimal system.*



duodenum \ˌd(y)ü-ə-'dē-nəm\ *n.*

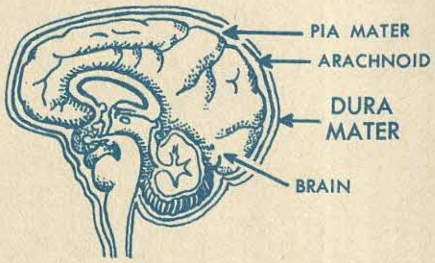
ANATOMY and ZOOLOGY. The upper, or first, portion of the small intestine.

After food is partially digested in the stomach, it is forced into the DUODENUM.

duplication \ˌd(y)ü-pli-'kā-shən\ *n.*

1. BOTANY. The separation of a leaf or floral organ into two or more parts by division during development. 2. ZOOLOGY. The doubling of chromosomes during mitosis.

DUPLICATION *can cause lack of symmetry in the parts of a flower.*



dura mater \'d(y)ür-ə-ˌmāt-ər\

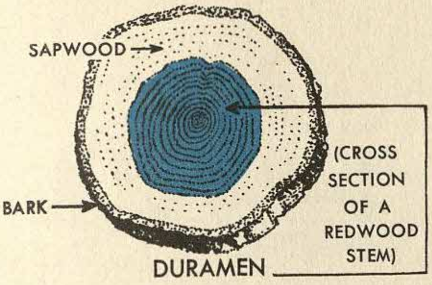
ANATOMY. The tough, fibrous membrane that encloses the brain and surrounds the spinal cord.

The DURA MATER *is the outermost of the three membranes that cover the brain and spinal cord.*

duramen \d(y)u̇-'rā-mən\ *n.*

BOTANY. The older hard, tough center of a tree made up of compacted dead tissues; also called heartwood.

DURAMEN *usually can be distinguished by its color, which is darker than that of the surrounding sapwood.*



dust-cloud hypothesis \'dəst-ˌklau̇d hī-'päth-ə-səs\

ASTRONOMY. A theory that the solar system was formed from whirling dust. The pressure of starlight forced the dust molecules together to form a rotating sun, while planets and their moons condensed from dust thrown off by the sun.

Both the DUST-CLOUD HYPOTHESIS *and the nebular hypothesis are based on the assumption that the solar system originated in a vast cloud of whirling dust and gas.*

dwarf star \'dwȯ(ə)rf 'stär\

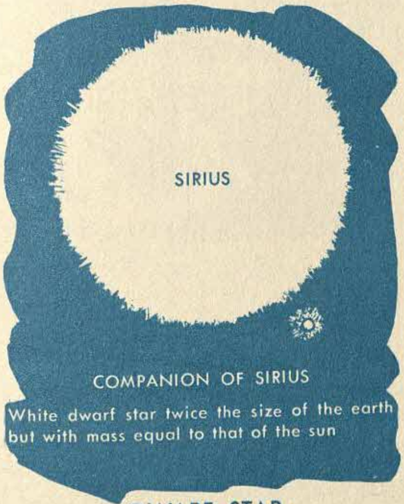
ASTRONOMY. A star of high density having its mass concentrated in a relatively-small volume and having a moderate luminosity or brightness.

A DWARF STAR *that is extremely hot and of very high density is called a white dwarf.*

dynameter \ˌdī-'nam-ət-ər\ *n.*

PHYSICS. An instrument for measuring the magnifying power of a telescope.

A DYNAMETER *is a useful tool in testing combinations of telescope lenses.*


SIRIUS
COMPANION OF SIRIUS
White dwarf star twice the size of the earth but with mass equal to that of the sun

DWARF STAR

dynamic equilibrium \dī-'nam-ik ˌē-kwə-'lib-rē-əm\

CHEMISTRY and PHYSICS. A situation in which two opposing forces or processes counteract each other and produce no net change. In the case of processes, one process is the reverse of the other, and each goes on at the same rate.

In a sealed water bottle, the liquid level does not change because evaporation and condensation are in DYNAMIC EQUILIBRIUM.

dynamics \dī-'nam-iks\ *n.*

PHYSICS. A branch of physics or mechanics that deals with forces that cause or affect motion.

Newton's three laws of motion are an important part of DYNAMICS.

dynamite \'dī-nə-ˌmīt\ *n.*

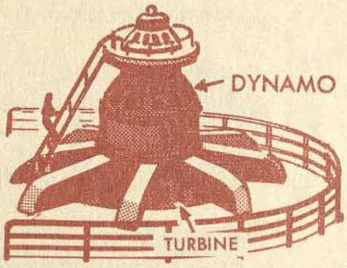
CHEMISTRY. An explosive consisting of nitroglycerin and an absorbent, heat-resistant material, usually diatomaceous earth.

DYNAMITE *is less likely to explode accidentally than is pure nitroglycerin.*

dynamo \'dī-nə-ˌmō\ *n.*

ENGINEERING and PHYSICS. A machine that converts mechanical energy into electrical energy, or electrical energy into mechanical energy, by magnetic induction.

A DYNAMO *may be used as either a generator or a motor.*



dynamoelectric \ˌdī-nə-mō-ə-'lek-trik\ *adj.*

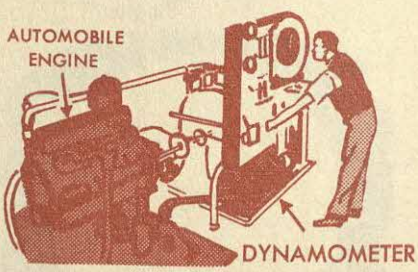
PHYSICS. Referring to the conversion of mechanical energy into electrical energy, or electrical energy into mechanical energy.

A DYNAMOELECTRIC *amplifier is often used in control systems for the movement of antiaircraft guns or radar antennas.*

dynamometer \ˌdī-nə-'mäm-ət-ər\ *n.*

A device used to measure mechanical power, such as that produced by an engine; also, an instrument that measures force produced by muscles.

A DYNAMOMETER *is necessary in determining horsepower produced by different fuels in a test engine.*



dyne \'dīn\ *n.*

PHYSICS. A fundamental unit of force in the metric system equal to the unbalanced force required to give one gram of mass an acceleration of one centimeter per second per second.

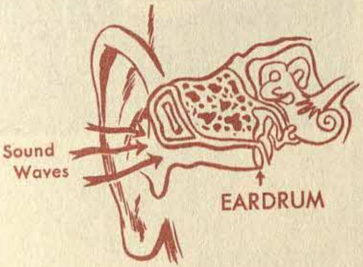
The DYNE *is such a small unit of force that, for practical purposes, the newton, equaling 100,000 dynes, is used.*

dystrophy \'dis-trə-fē\ *n.*

MEDICINE and ZOOLOGY. A weakened condition resulting from poor nutrition.

Lack of rainfall over a prolonged period can produce DYSTROPHY *in wild rabbits, who are dependent upon abundant vegetation.*

E



eardrum \'i(ə)r ˌdrəm\ *n.*

ANATOMY and ZOOLOGY. The tympanic membrane separating the outer ear from the middle ear and conducting vibrations to other auditory structures.

The EARDRUM *vibrates when sound waves strike it.*

earth \'ərth\ *n.*

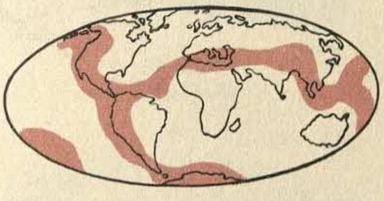
EARTH SCIENCE. Soil or loose material on land surfaces, as contrasted with rock; also, land surfaces as distinguished from water and air; also, the planet itself (Earth).

The large amount of EARTH *available for agricultural purposes is one of this country's most important natural resources.*

earthquake \'ərth-ˌkwāk\ *n.*

EARTH SCIENCE. A tremor or quaking of the earth's crust, resulting either from underground volcanic activity or from the shifting of rock beneath the surface.

An EARTHQUAKE *produces shock waves that travel in all directions from its center.*



EARTHQUAKE BELT

earthquake belt \'ərth-ˌkwāk 'belt\

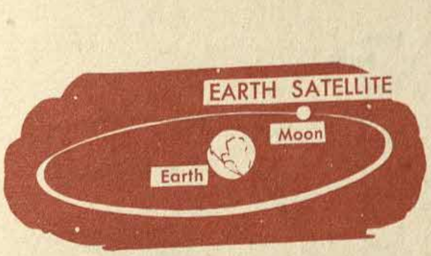
EARTH SCIENCE. Either of two areas, in the Pacific or in the Mediterranean, where earthquakes are most likely to occur because of weaknesses in the crust of the earth.

An EARTHQUAKE BELT *is an area containing active volcanoes and many young mountains.*

earth satellite \'ərth 'sat-ᵊl-ˌīt\

ASTRONAUTICS and ASTRONOMY. Any object, either natural or artificial, revolving around the earth.

The moon is a natural EARTH SATELLITE.



earth science \'ərth 'sī-ən(t)s\

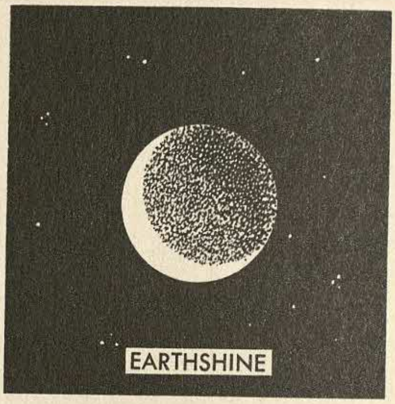
The study of the earth, its materials and the forces acting on them, and the earth's relationships to other bodies in space.

The study of EARTH SCIENCE *involves basic concepts of geology, meteorology, astronomy, chemistry and physics.*

earthshine \ˈərth-ˌshīn\ *n.*

ASTRONOMY. Sunlight reflected from the earth; usually, the faint illumination of the ordinarily-dark portion of the moon by sunlight reflected from the earth.

EARTHSHINE *can be observed most easily during crescent phases of the moon.*



eccentricity \ˌek-ˌsen-ˈtris-ət-ē\ *n.*

MATHEMATICS. In a conic section, the ratio of the distance between any point of the curve and a focus to the distance between the point and the directrix associated with the focus. The ratio is a constant that expresses how a conic deviates from a circle.

The ECCENTRICITY *of a circle is always zero.*

eclipse \i-ˈklips\ *n.*

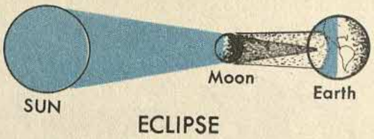
ASTRONOMY. Any temporary overshadowing of the light of one celestial body by another celestial body.

A lunar ECLIPSE *occurs when the earth's shadow falls on the moon.*

eclipsing binary \i-ˈklips-iŋ ˈbī-nə-rē\

ASTRONOMY. A pair of stars that orbit around each other and whose plane of orbital rotation is in the line of sight as they are viewed from the earth so that each star is alternately hidden (completely or partially) during each revolution.

Astronomers detect an ECLIPSING BINARY *by its rhythmic fluctuations in brightness.*



ECLIPSE
Solar Eclipse

ecliptic \i-ˈklip-tik\ *n.*

ASTRONOMY. The great circle of the celestial sphere that is the sun's apparent annual path among the stars; also, the path of the earth as it would appear from the sun.

The ECLIPTIC *is so tilted that it intersects the celestial equator at two points, the vernal equinox and the autumnal equinox.*

ecology \i-ˈkäl-ə-jē\ *n.*

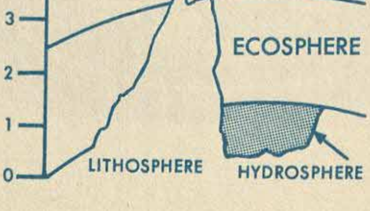
BIOLOGY. The study of the relationships among living organisms and between living organisms and their environment.

One function of ECOLOGY *is to determine why certain plants or animals are able to live only in particular locations.*

ecosphere \ˈek-ō-ˌsfi(ə)r\ *n.*

EARTH SCIENCE. That region of the atmosphere in which normal breathing is possible.

The ECOSPHERE *extends to an altitude of about 13,000 feet above sea level.*



ecosystem \'ek-ō-ˌsis-təm\ *n.*

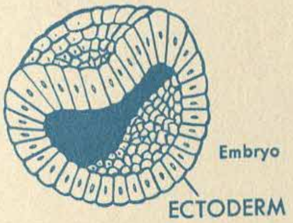
BIOLOGY and EARTH SCIENCE. A self-sustaining community of organisms that includes their inorganic environment.

Soil type and climate may be two factors in an ECOSYSTEM.

ecotone \'ek-ō-ˌtōn\ *n.*

BIOLOGY. The boundary area between two different ecological communities.

Within an ECOTONE, *organisms from the two adjacent communities often mix.*



ectoderm \'ek-tə-ˌdərm\ *n.*

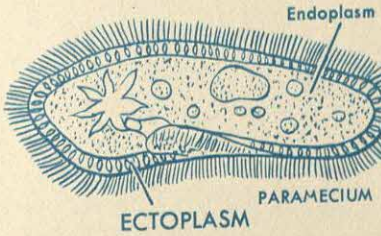
ZOOLOGY. The outer-cell layer of an animal embryo from which the nervous system, the skin, the teeth and other external features are developed; also, the outer layer of cells of the body in some multicellular lower animals.

The ECTODERM *of the hydra contains both sensory and stinging cells.*

ectoparasitic \ˌek-(ˌ)tō-ˌpar-ə-'sit-ik\ *adj.*

BIOLOGY. Referring to a parasite that lives on the outside of its host, and is harmful to it.

Lice are ECTOPARASITIC *insects, living on mammals and sucking their blood.*



ectoplasm \'ek-tə-ˌplaz-əm\ *n.*

BIOLOGY. The clear, thin, outermost layer of cytoplasm in a cell.

The ECTOPLASM *of a cell is located inside the cell membrane and surrounds the endoplasm.*

edaphic biome \i-'daf-ik 'bī-ˌōm\

BIOLOGY and EARTH SCIENCE. An earth zone characterized by the nature of its soil.

The desert areas constitute an EDAPHIC BIOME.

eddy currents \'ed-ē 'kər-ənts\

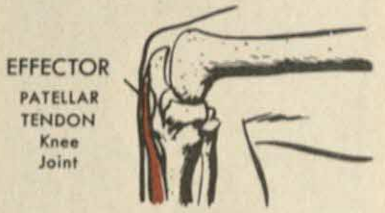
PHYSICS. Electrical currents, or eddies, induced within metal by a variation of a magnetic field through the metal; also known as Foucault currents.

Such devices as the watt-hour meter and the magnetic automobile speedometer depend upon EDDY CURRENTS *for their operation.*

Edison effect \'ed-ə-sən i-'fekt\

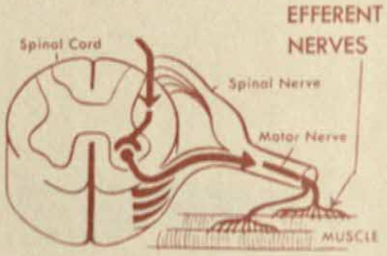
PHYSICS. The emission or liberation of electrons from an incandescent filament that is generally heated by an electrical current; also, the flow of emitted electrons from a heated wire to a nearby positively-charged plate.

The EDISON EFFECT *was named for Thomas A. Edison, who noted the effect while he was experimenting with the incandescent light bulb.*



effector \i-'fek-tər\ *n.*
ANATOMY and ZOOLOGY. An organ, such as a muscle or gland, by means of which an animal responds to a stimulus; also, a nerve or nerve end organ that stimulates a muscle to contract or a gland to secrete.

In a reflex action, a muscle that contracts is an EFFECTOR.



efferent nerves \'ef-ə-rənt 'nərvz\
ANATOMY. Nerves that carry impulses away from nerve centers to muscles and glands.

The EFFERENT NERVES *of the heart consist of a pair of accelerator nerves and a pair of inhibitory nerves.*

effervescence \ˌef-ər-'ves-ᵊn(t)s\ *n.*
CHEMISTRY. The formation of bubbles or foam within a liquid and on its surface as a result of escaping gases.

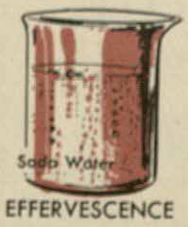
Carbon dioxide produces the EFFERVESCENCE *in sodas.*

efficiency \i-'fish-ən-sē\ *n.*
PHYSICS. The ratio between the useful work output of a machine, storage battery or other device and the energy of work input, generally expressed as a percentage.

Because of friction, no machine has an EFFICIENCY *as high as 100 percent.*

efflorescence \ˌef-lə-'res-ᵊn(t)s\ *n.*
CHEMISTRY. The crumbling of a crystalline salt (a hydrate) to a powder due to loss of water to the atmosphere; also, the powder produced in this way.

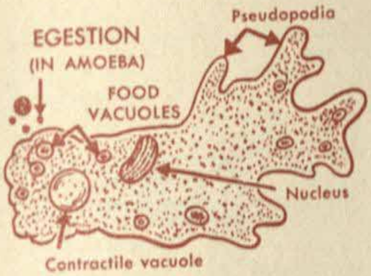
EFFLORESCENCE *of a hydrated salt occurs when the vapor pressure of the hydrate and its decomposition product is greater than the partial pressure of atmospheric vapor.*



EFFERVESCENCE

effusion \i-'fyu-zhən\ *n.*
1. PHYSICS. The movement of a gas through a porous material or substance; also, the flow of a gas through a small opening.
2. MEDICINE. The flow of a fluid into a body cavity or tissue.

The rate of EFFUSION *of a gas depends in part upon its density.*


EGESTION
(IN AMOEBA)

egestion \i-'jes(h)-chən\ *n.*
PHYSIOLOGY and ZOOLOGY. The casting out, or eliminating, of indigestible body wastes or material.

In an amoeba, EGESTION *takes place as the protoplasm flows away from the material left in the food vacuole.*

egg \'eg\ *n.*
ZOOLOGY. A reproductive, or germ, cell produced by the female; an ovum.

An EGG *usually must be fertilized before an embryo can develop.*

Einstein shift \'īn-,stīn 'shift\
ASTRONOMY. In a light spectrum, a slight moving of lines toward the red.

The EINSTEIN SHIFT *has been observed in light coming from dense stars, such as white dwarfs.*

ELASTICITY
(OF COIL SPRING)

elastic collision \i-'las-tik kə-'lizh-ən\
PHYSICS. A collision of two particles in which there is no loss of kinetic energy or transference of kinetic energy to internal energy, and in which the momentum of the colliding particles is redistributed between them.

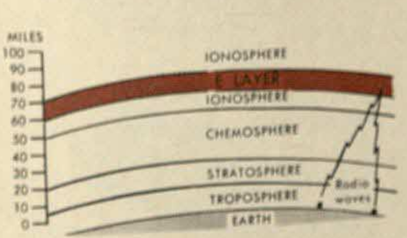
Colliding marbles or pool balls provide a good visual example of ELASTIC COLLISION.

elasticity \i-,las-'tis-ət-ē\ *n.*
PHYSICS. The ability of a distorted body or system to resume its original shape and size when the cause of distortion is removed; flexibility or springiness.

ELASTICITY *is caused by forces between the molecules of the elastic substance.*

elastic limit \i-'las-tik 'lim-ət\
PHYSICS. The greatest stress that an elastic material can withstand without becoming permanently deformed.

In engineering, it is often essential to know the ELASTIC LIMIT *of structural material.*



E LAYER

E layer \'ē 'lā-ər\
EARTH SCIENCE. A layer of concentrated ionization within the ionosphere between altitudes of 50 and 90 miles.

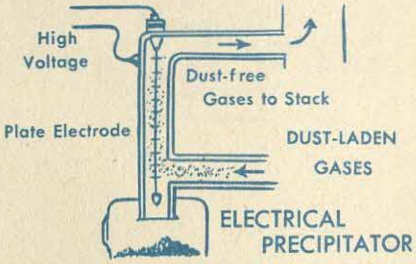
The E LAYER *reflects low-frequency radio waves back to the earth's surface.*

electrical conduction \i-'lek-tri-kəl kən-'dək-shən\
1. PHYSICS. The transmission of electricity from one point to another through matter. 2. CHEMISTRY. In an electrolyte, the movement of positive ions toward the negative electrode and the movement of negative ions toward the positive electrode.

Glass is an electric insulator because it does not permit ELECTRICAL CONDUCTION.

electrical engineering \i-'lek-tri-kəl ˌen-jə-'ni(ə)r-iŋ\
ENGINEERING. The branch of engineering dealing with the theory and practice of the generation, transmission and use of electrical energy.

The branch of ELECTRICAL ENGINEERING *that is concerned with lighting systems is called illuminating engineering.*



electrical precipitator \i-'lek-tri-kəl pri-'sip-ə-ˌtāt-ər\
ENGINEERING. A device that removes charged particles from a substance by attracting them to an oppositely-charged screen or plate.

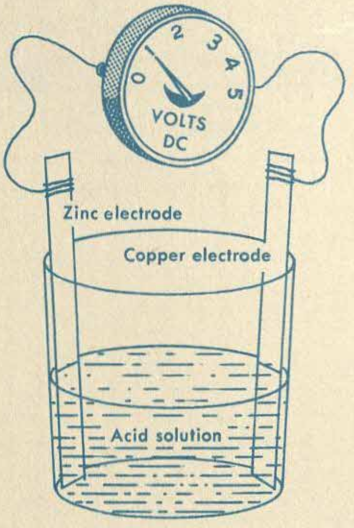
An ELECTRICAL PRECIPITATOR *is used in smoke stacks to reduce the smoke in industrial areas.*

electrical repulsion \i-'lek-tri-kəl ri-'pəl-shən\
CHEMISTRY and PHYSICS. A phenomenon of electricity in which like electric charges, either positive or negative, repel each other.

ELECTRICAL REPULSION *occurs when a negatively-charged rod is brought close to a negatively-charged piece of paper.*

electrical resistance \i-'lek-tri-kəl ri-'zis-tən(t)s\
PHYSICS. The property of a substance that opposes a flow of electrons through it.

A good conductor has low ELECTRICAL RESISTANCE.



ELECTRIC CELL

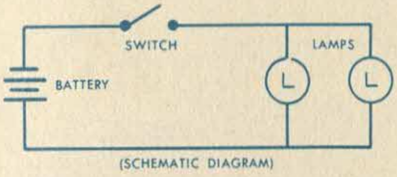
electric cell \i-'lek-trik 'sel\
CHEMISTRY and PHYSICS. A device consisting of electrodes (of different metals or of carbon and a metal) placed in an acid or salt solution and producing a flow of electrons (between the electrodes and through the circuit formed) when the electrodes are connected outside the device; also, a device of similar structure used for electroplating a metal by means of an electric current.

An ELECTRIC CELL *changes chemical energy into electrical energy or electrical energy into chemical energy.*

electric charge \i-'lek-trik 'chärj\

CHEMISTRY and PHYSICS. A quantity of electricity, or an excess or a deficiency of electrons.

Benjamin Franklin named the two different kinds of ELECTRIC CHARGE *positive charge and negative charge.*



ELECTRIC CIRCUIT

electric circuit \i-'lek-trik 'sər-kət\

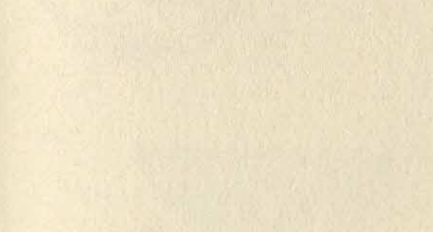
PHYSICS. The complete route of an electric current from a source, such as one terminal of a battery or generator, through the resistance of an electrically-powered mechanism and back to the other terminal.

An ELECTRIC CIRCUIT *can be controlled by a switch that opens or closes the path of the current.*

electric current \i-'lek-trik 'kər-ənt\

PHYSICS. A flow of electrons through a conductor.

An ELECTRIC CURRENT *is essentially a flow of electric energy.*



ELECTRIC EYE

electric eye \i-'lek-trik 'ī\

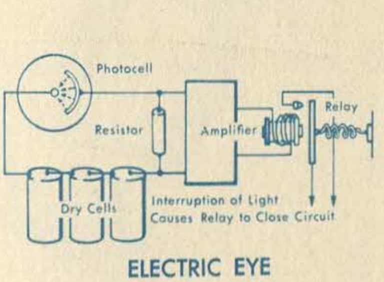
ENGINEERING. A photoelectric cell that controls and operates devices automatically. Light falling upon a light-sensitive metal surface causes electrons to be given off by the metal, and the electrons are attracted to a positively-charged plate in the eye, or tube, producing a slight current that is externally amplified to work the device as the light is turned on and off.

An ELECTRIC EYE *is commonly used to activate the automatic mechanisms that open and close supermarket doors.*

electric field \i-'lek-trik 'fēld\

PHYSICS. A region in which an electrical force is exerted on an electrical charge present within the region.

An ELECTRIC FIELD *in the region between two objects, one positively charged and one negatively charged, should not be confused with a magnetic field.*



electric generator \i-'lek-trik 'jen-ə-ˌrāt-ər\

ENGINEERING. A machine that changes mechanical energy into electrical energy in the form of alternating or direct current; generally called a dynamo.

In an ELECTRIC GENERATOR, *the current is produced in the coils of the armature.*

electricity \i-'lek-'tris-ət-ē\ *n.*

ENGINEERING and PHYSICS. A form of energy having the electron as its fundamental unit. When the electrical charge is at rest, it is referred to as static. When in motion, it is referred to as current.

A wire in which a stream of electrons is flowing carries a current of ELECTRICITY.

electric motor \i-'lek-trik 'mōt-ər\

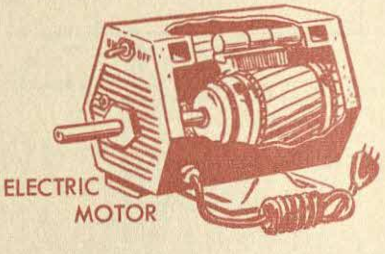
ENGINEERING. A machine that transforms electrical energy into mechanical energy.

The starter of an automobile is a direct current ELECTRIC MOTOR.

electric power \i-'lek-trik 'pau̇(-ə)r\

PHYSICS. The product of an electric current, in amperes, and an electromotive force, in volts.

The most commonly-used unit of ELECTRIC POWER *is the kilowatt.*



electrify \i-'lek-trə-ˌfī\ *v.*

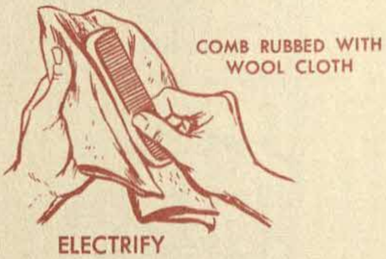
PHYSICS. To form a static charge of electricity on an object; also, to send a current of electricity through a liquid, solid or gas.

Under certain conditions, it is possible to ELECTRIFY *your body by scuffing your feet along a rug.*

electrocardiograph \i-ˌlek-(ˌ)trō-'kärd-ē-ə-ˌgraf\ *n.*

MEDICINE. An instrument that records variations in the electric currents produced by contractions of various heart muscles. The record produced is called an electrocardiogram.

A physician uses an ELECTROCARDIOGRAPH *to diagnose heart ailments.*



electrochemical equivalent \i-ˌlek-(ˌ)trō-'kem-i-kəl i-'kwiv-ə-lənt\

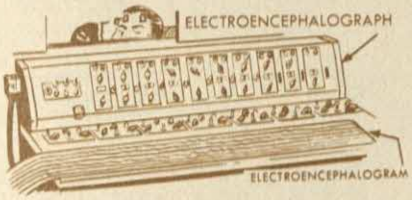
CHEMISTRY and PHYSICS. The mass of an element liberated in electrolysis by one coulomb (the flow of one ampere of current in one second) of electricity.

The ELECTROCHEMICAL EQUIVALENT *of hydrogen is 0.00001036 gram.*

electrochemistry \i-ˌlek-(ˌ)trō-'kem-ə-strē\ *n.*

CHEMISTRY. The branch of science that deals with the chemical effects produced by electricity and the electrical effects of chemical action.

Through ELECTROCHEMISTRY, *it is possible to plate silver over less expensive metals.*



ELECTROENCEPHALOGRAPH

electrode \i-'lek-ˌtrōd\ *n.*

CHEMISTRY and PHYSICS. The terminal in an electric circuit that connects the electrical conductor, generally a wire, with a conducting substance.

In a chemical cell, each ELECTRODE *is an anode or a cathode.*

electrodynamics \i-ˌlek-trō-(ˌ)dī-'nam-iks\ *n.*

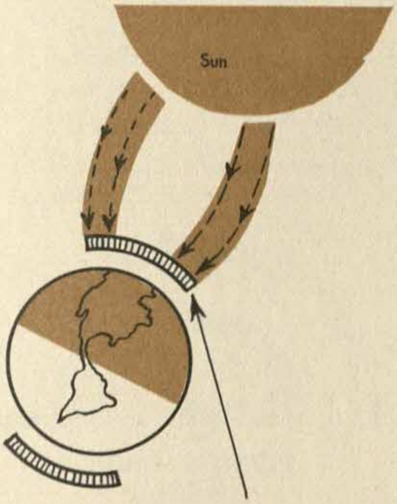
PHYSICS. That part of physics that deals with moving electricity and its properties and with the interaction of current electricity and magnetism.

The development of electric motors and generators resulted from the principles of ELECTRODYNAMICS.

electroencephalograph \i-ˌlek-(ˌ)trō-en-'sef-ə-lō-ˌgraf\ *n.*

MEDICINE. An instrument for recording electric currents developed in the brain. Electrodes applied to the scalp or directly to the surface of the brain pick up and relay the electric impulses to the recording part of the instrument.

The record produced by an ELECTROENCEPHALOGRAPH *aids in the diagnosis of major disorders of the brain.*



ELECTROJET

electrojet \i-'lek-trə-ˌjet\ *n.*

EARTH SCIENCE. Either of two bands of electric current in the ionosphere, one occurring in polar regions and the other in the equatorial region; a moving layer of ionized atmospheric particles.

Disturbances on the surface of the sun affect the ELECTROJET.

electrokinetics \i-ˌlek-trō-kə-'net-iks\ *n.*

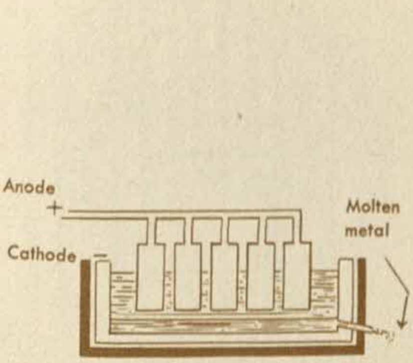
PHYSICS. That part of physics concerned with the movement of electrified particles, particularly in electric and magnetic fields or in circuits and networks.

ELECTROKINETICS *is contrasted with electrostatics, or electricity at rest.*

electroluminescent \i-ˌlek-(ˌ)trō-ˌlü-mə-'nes-ᵊnt\ *adj.*

PHYSICS. Referring to light resulting from the direct conversion of electrical energy into light energy.

The common neon sign is ELECTROLUMINESCENT.



ELECTROLYSIS

electrolysis \i-ˌlek-'träl-ə-səs\ *n.*

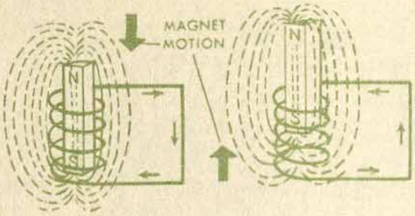
CHEMISTRY. The decomposition of a chemical compound in solution by the action of an electric current that passes through the solution or through the compound in molten form.

Magnesium, copper and many other metals are obtained from their natural ores and compounds by ELECTROLYSIS.

electrolyte \i-'lek-trə-ˌlīt\ *n.*

CHEMISTRY. A compound that, in solution or in the molten state, conducts electricity; also, a conducting solution containing such a compound.

A solution of an acid, a base or a salt in water is an ELECTROLYTE.



ELECTROMAGNETIC INDUCTION

electromagnetic field \i-ˌlek-trō-ˌmag-'net-ik 'fēld\

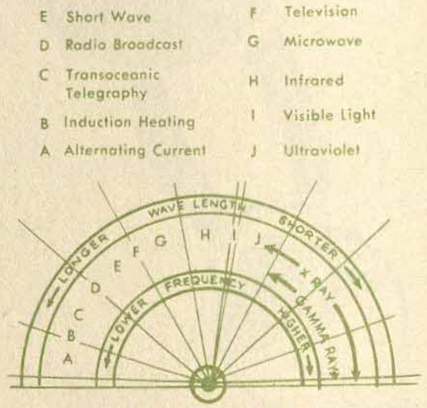
PHYSICS. A region through which alternating magnetic lines of force and electrical lines of force move at right angles to each other.

An ELECTROMAGNETIC FIELD *is created by electrons oscillating in an electrical conductor.*

electromagnetic induction \i-ˌlek-trō-ˌmag-'net-ik in-'dək-shən\

PHYSICS. The production of electromotive force, or voltage, in a closed circuit when a conductor in the circuit moves across magnetic lines of force.

The operation of an electrical transformer is based on the principle of ELECTROMAGNETIC INDUCTION.



ELECTROMAGNETIC SPECTRUM

electromagnetic radiation \i-ˌlek-trō-ˌmag-'net-ik ˌrād-ē-'ā-shən\

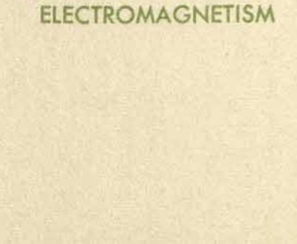
PHYSICS. Alternating magnetic lines of force (field) and electrical lines of force (field) that are produced by oscillating electric charges and that are at right angles to each other.

Light waves, radio waves and X rays are examples of ELECTROMAGNETIC RADIATION.

electromagnetic spectrum \i-ˌlek-trō-ˌmag-'net-ik 'spek-trəm\

PHYSICS. The continuous range of frequencies of electromagnetic radiations from the lowest to the highest wavelengths; also, a chart or diagram that represents the range of electromagnetic waves according to frequency or wavelength.

The visible light spectrum is a very small portion of the ELECTROMAGNETIC SPECTRUM.



ELECTROMAGNETISM

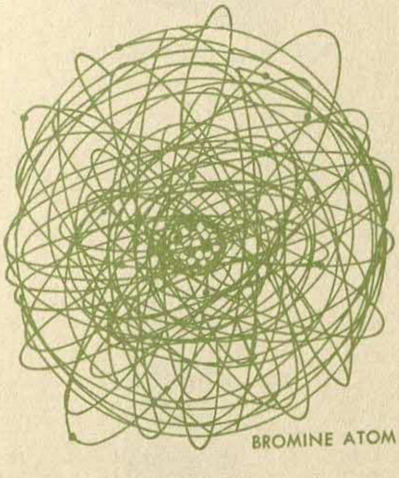
electromagnetism \i-ˌlek-trō-'mag-nə-ˌtiz-əm\ *n.*

PHYSICS. Magnetism produced by an electric current; also, the relationship between electricity and magnetism.

ELECTROMAGNETISM *is produced in the region around an electrical conductor when a current of electricity, either alternating or direct, flows through the conductor.*

Lithium Li 3
Potassium K 19
Calcium Ca 20
Sodium Na 11
Magnesium Mg 12
Aluminum Al 13
Manganese Mn 25
Zinc Zn 30
Chromium Cr 24
Iron Fe 26
Cadmium Cd 48
Cobalt Co 27
Nickel Ni 28
Tin Sn 50
Lead Pb 82
Hydrogen H 1
Bismuth Bi 83
Copper Cu 29
Mercury Hg 80
Silver Ag 47
Platinum Pt 78
Gold Au 79

ELECTROMOTIVE SERIES



ELECTRON CLOUD

electrometer \i-ˌlek-'träm-ət-ər\ *n.*

PHYSICS. A mechanism, balance or a high input impedance amplifier used to determine voltage differences by the amount of force attracting or repelling charged bodies, or to measure the potential difference between two points in a circuit.

The ELECTROMETER *is a useful instrument in electronics laboratories.*

electromotive force \i-ˌlek-trə-'mōt-iv 'fō(ə)rs\

PHYSICS. The force that causes electricity to move; the potential difference created by an electrical source; voltage; *abbr.* EMF.

An ELECTROMOTIVE FORCE *is measured in volts.*

electromotive series \i-ˌlek-trə-'mōt-iv 'si(ə)r-(ˌ)ēz\

CHEMISTRY and PHYSICS. A list of elements, usually metals plus hydrogen, arranged in the order of their decreasing oxidation potential (the order in which each metal can displace those below it from their compounds or displace the ions of the lower elements in the series from water solutions).

In the ELECTROMOTIVE SERIES, *the most active element is lithium, and the least active is gold.*

electron \i-'lek-ˌträn\ *n.*

CHEMISTRY and PHYSICS. An elementary electric particle having a unitary negative charge and found in the shells of atoms and in static or current electricity; a unit particle of electricity.

The mass of an ELECTRON *is about 1/1,837 of the mass of a proton.*

electron cloud \i-'lek-ˌträn 'klaủd\

CHEMISTRY and PHYSICS. A random arrangement of negatively-charged particles, or electrons, moving rapidly about the nucleus of an atom.

Early diagrams of atomic structure showed electrons circling the nucleus in fixed circular paths, but a more recent concept is that of an ELECTRON CLOUD *surrounding the nucleus.*

electronegative element \i-ˌlek-trō-'neg-ət-iv 'el-ə-mənt\

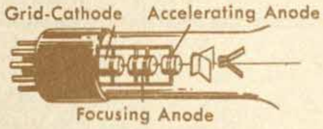
CHEMISTRY. An element whose atoms have a relatively-great tendency to attract electrons; generally, an acid-forming element.

An ELECTRONEGATIVE ELEMENT *is generally a nonmetal.*

electron gun \i-'lek-ˌträn 'gən\

PHYSICS. In a cathode-ray tube, the heated element, or cathode, that emits a beam of electrons and the devices that form or control the electron beam.

An ELECTRON GUN *is an essential part of an oscilloscope and of the picture tube in a television receiver.*

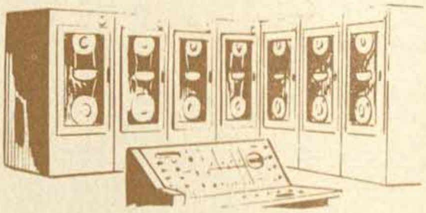


ELECTRON GUN

electronic computer \i-ˌlek-'trän-ik kəm-'pyüt-ər\

ENGINEERING. Any of various calculators or computers that operate electronically.

An ELECTRONIC COMPUTER *generally solves a complete mathematical problem, but mechanical calculators usually perform only one mathematical operation at a time.*



ELECTRONIC COMPUTER

electronic data processing \i-ˌlek-'trän-ik 'dāt-ə 'präs-ˌes-iŋ\

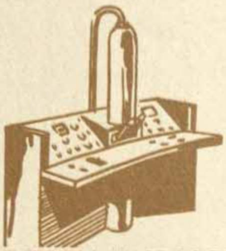
ENGINEERING and MATHEMATICS. The function of any computer that performs its calculations electronically; *abbr.* EDP.

ELECTRONIC DATA PROCESSING *has been used successfully in the life sciences, as well as in the physical sciences and in manufacturing and business procedures.*

electron microscope \i-'lek-ˌträn 'mī-krə-ˌskōp\

A microscope using a beam of electrons, rather than light rays, and a series of magnetic electron lenses to focus the electron beam on a fluorescent screen or on a photographic plate.

An ELECTRON MICROSCOPE *is used to magnify extremely-small objects that cannot be seen with an optical microscope.*



ELECTRON MICROSCOPE

electron shell \i-'lek-ˌträn 'shel\

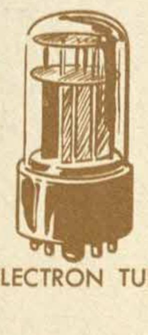
CHEMISTRY and PHYSICS. A space around the nucleus of an atom in which electrons move at a given average distance from the nucleus.

Each ELECTRON SHELL *of an atom corresponds to the main energy level of the electrons, with the electrons in the outermost shell having the greatest amount of energy.*

electron tube \i-'lekˌträn 't(y)üb\

ENGINEERING and PHYSICS. A partially- or completely-evacuated tube in which electrons are emitted by a hot cathode and are attracted to a plate. In passing through the evacuated space, the electrons are affected by other elements of the tube, such as one or more grids.

A flow of electrons in an ELECTRON TUBE *results when a filament and a plate are placed in an electrical circuit so that the plate is positive with respect to the filament.*

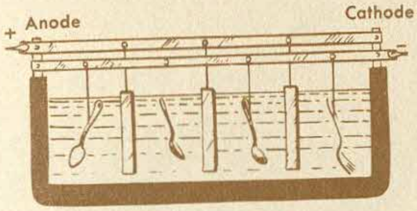


ELECTRON TUBE

electron volt \i-ˈlek-ˌträn ˈvōlt\

PHYSICS. A unit of energy equal to 1.602×10^{-12} erg that indicates the quantity of energy an electron gains in moving from one electric field to another whose potential is greater by one volt; *abbr.* EV.

Because the ELECTRON VOLT *is a minute amount of energy, the unit million electron volts (MEV) is customarily used in dealing with large quantities.*



ELECTROPLATE

electrophoresis \i-ˌlek-trə-fə-ˈrē-səs\ *n.*

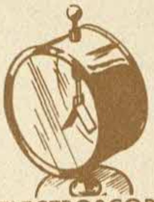
CHEMISTRY and PHYSICS. The movement of charged colloidal particles in a fluid to either a positive electrode or a negative electrode.

Biochemists use ELECTROPHORESIS *to separate and study various proteins.*

electroplate \i-ˈlek-trə-ˌplāt\ *v.*

ENGINEERING. To deposit a coating of rubber or of a metal, such as silver or nickel, by electrolysis.

Automobile manufacturers ELECTROPLATE *bumpers with chrome.*



ELECTROSCOPE
(CHARGED)

electroscope \i-ˈlek-trə-ˌskōp\ *n.*

PHYSICS. An instrument that detects small charges of electricity or that measures small voltages.

Operation of an ELECTROSCOPE *depends upon the forces between electrically-charged bodies.*

electrostatic generator \i-ˌlek-trə-ˈstat-ik ˈjen-ə-ˌrāt-ər\

PHYSICS. A high-voltage generator that creates an electrical potential by mechanical transportation of electrical charges to a point where they are accumulated and form a very high voltage.

The Van de Graaff ELECTROSTATIC GENERATOR *is used for experimental work in the field of nuclear physics.*

ELECTROSTATIC
GENERATOR

electrostatics \i-ˌlek-trə-ˈstat-iks\ *n.*

PHYSICS. The branch of electricity that deals with static electricity, or electricity at rest, and with the laws relating to the effects created by electric charges.

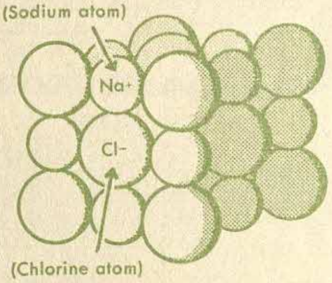
Benjamin Franklin, using his kite, conducted one of the first experiments in ELECTROSTATICS.

electrostatic unit \i-ˌlek-trə-'stat-ik 'yü-nət\
PHYSICS. A basic unit or measurement of an electric charge; *abbr.* esu.

An ELECTROSTATIC UNIT *of electricity in a vacuum will repel an equal charge with the force of one dyne at a distance of one centimeter from the charge.*

electrovalence \i-ˌlek-trō-'vā-lən(t)s\ *n.*
CHEMISTRY. The electrostatic bonding force between ions that are formed by the transfer of one or more electrons from the outer shell of an atom or atoms of one element to the outer shell of an atom or atoms of another element. A compound results from the bonding.

ELECTROVALENCE *is typical of those compounds whose water solutions conduct electricity.*



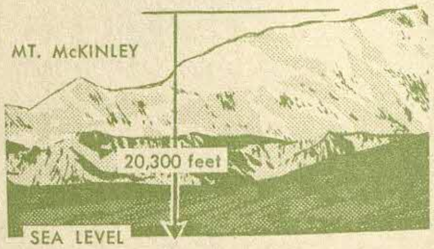
ELECTROVALENCE

element \'el-ə-mənt\ *n.*
1. CHEMISTRY. A substance that cannot be decomposed into a simpler substance by ordinary chemical means. 2. MATHEMATICS. Any object or symbol belonging to a specified set, as one of the numbers appearing in a determinant or matrix; also, the generatrix of a curve, surface or volume as described by a moving point, curve or surface.

All the atoms of a given ELEMENT *have the same atomic number.*

elementary particle \ˌel-ə-'ment-ə-rē 'pärt-i-kəl\
CHEMISTRY and PHYSICS. Originally, any particle of matter thought to have unique intrinsic properties and permanent existence; loosely, any subatomic particle that can convert into another particle or to radiation, as an electron, a positron, a meson, a neutrino or a photon.

A neutron is an ELEMENTARY PARTICLE *found in the nucleus of an atom.*



ELEVATION

elevation \ˌel-ə-'vā-shən\ *n.*
EARTH SCIENCE. A specific altitude, or height, above sea level.

The ELEVATION *of Mount McKinley is 20,300 feet.*

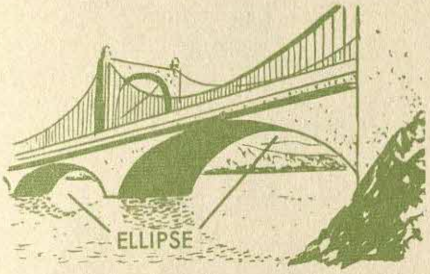
elimination \i-ˌlim-ə-'nā-shən\ *n.*
1. MATHEMATICS. A process by which an equation in one variable may be derived from a set of equations involving a number of variables. 2. PHYSIOLOGY. The passing from the body of solid, liquid and gaseous wastes.

Using the addition axiom will result in the ELIMINATION *of the variable* y *in the equations* $2x + y = 10$ *and* $4x - y = 20$.

ellipse \i-ˈlips\ *n.*

MATHEMATICS. A conic section formed by a plane cutting a right circular cone in such a way that the plane is not parallel to any element of the cone; also, the set of points the sum of whose distances from two fixed points, called foci, is constant.

Engineers may use the ELLIPSE *in planning the arches of a bridge.*



ellipsoid \i-ˈlip-ˌsȯid\ *n.*

MATHEMATICS. A quadric surface or geometric solid, each of whose plane sections is an ellipse.

An ELLIPSOID *formed by rotating an ellipse about one of its axes is a spheroid.*

ellipticity \i-ˌlip-ˈtis-ət-ē\ *n.*

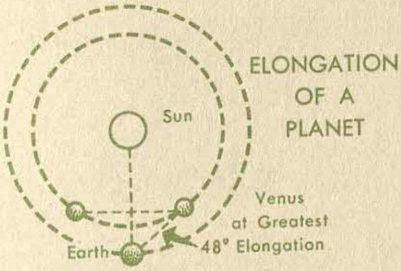
MATHEMATICS. The relative amount of deviation of an ellipse or of an ellipsoid from the shape of a circle or of a sphere.

The ELLIPTICITY *of the earth is about 1/300.*

elongation of a planet \i-ˌlȯŋ-ˈgā-shən əv ˈā ˈplan-ət\

ASTRONOMY. The angular distance of a planet from the sun, measured in degrees.

The greatest ELONGATION OF A PLANET, *that of Venus, amounts to 48 degrees.*



eluviation \(ˌ)ē-ˌlü-vē-ˈā-shən\ *n.*

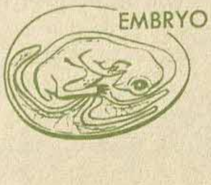
EARTH SCIENCE. The transportation of dissolved or suspended soil material, especially colloids, within the soil.

ELUVIATION *results in a change of soil composition by adding or removing minerals.*

emanation \ˌem-ə-ˈnā-shən\ *n.*

CHEMISTRY and PHYSICS. One of the radioactive, gaseous substances created when radium disintegrates.

One EMANATION *produced by the distintegration of radium is radon.*



embryo \ˈem-brē-ˌō\ *n.*

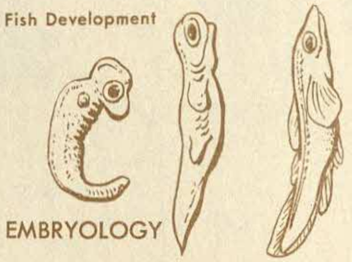
1. ZOOLOGY. A young animal in the earliest stages of development. 2. BOTANY. The germ, or partially-developed plant, contained in a seed.

The hard shell of a bird's egg protects the delicate EMBRYO.

embryology \ˌem-brē-ˈäl-ə-jē\ *n.*

BIOLOGY. The branch of biology that deals with the stages in the formation and development of the embryo in plants and animals.

EMBRYOLOGY *is usually limited to the part of an individual's life history that extends from the union of the germ cells to the completion of its body structure.*



EMBRYOLOGY

emergence \i-ˈmər-jən(t)s\ *n.*

EARTH SCIENCE. A process by which a sea or lake bottom becomes dry land through a lowering of the water level or uplift of the land; also, the place where an underground stream comes to the surface.

EMERGENCE *has been proved by the discovery of marine fossils in areas well above the present sea level.*

emetic \i-ˈmet-ik\ *n.*

PHYSIOLOGY. A medicine or other substance that induces vomiting.

An EMETIC *is sometimes prescribed to rid the stomach of certain kinds of swallowed poisons.*

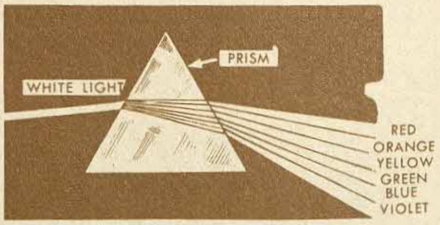
EMF

An abbreviation for electromotive force. See *electromotive force.*

emission \ē-ˈmish-ən\ *n.*

PHYSICS. The release, or discharge, of energy from a surface in such forms as heat, light or electrons.

The heating of the cathode in a radio tube results in the EMISSION *of electrons.*



EMISSION SPECTRUM

emission spectrum \ē-ˈmish-ən ˈspek-trəm\

ASTRONOMY and PHYSICS. The result of the dispersion of a beam of radiant energy, the component waves being arranged in the order of their wavelength.

The rainbow is an EMISSION SPECTRUM, *the red color having a long wavelength and the blue color a short wavelength.*

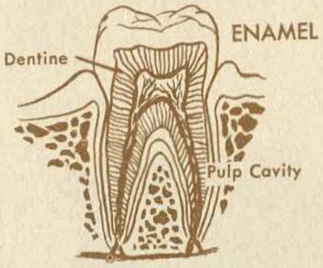
empirical \im-ˈpir-i-kəl\ *adj.*

Referring to knowledge based solely on experiment and observation and not necessarily supported by scientific principle.

An EMPIRICAL *generalization may be made without regard to scientific law or theory.*

empirical formula \im-'pir-i-kəl 'fȯr-myə-lə\
CHEMISTRY. A chemical formula that states the simplest numerical relationship of the atoms in a compound.

The EMPIRICAL FORMULA *for acetylene is CH, but the molecular formula is* C_2H_2.



emulsify \i-'məl-sə-ˌfī\ *v.*
CHEMISTRY. To transform into an emulsion.

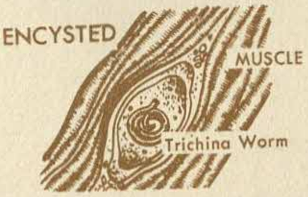
A film of soap molecules can be made to coat fine globules of oil and to EMULSIFY *them.*

emulsion \i-'məl-shən\ *n.*
CHEMISTRY. A colloidal suspension of very small droplets or fine particles of one liquid in another.

A common example of an EMULSION *is salad dressing.*

enamel \in-'am-əl\ *n.*
ANATOMY and ZOOLOGY. The hard, white coating on the teeth of most mammals and many other vertebrates.

ENAMEL *is composed chiefly of calcium and magnesium salts.*



encephalon\en-'sef-ə-ˌlän\ *n.*
ANATOMY. The brain.

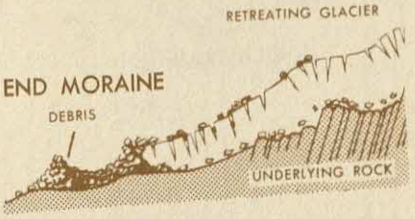
The ENCEPHALON *is the part of the central nervous system that is contained within the cranium.*

encysted \in-'sist-əd\ *adj.*
BIOLOGY. Covered on all sides or contained within a sac or capsule.

Trichinae are parasitic roundworms that become ENCYSTED *within the muscles of certain mammals.*

endemic \en-'dem-ik\ *adj.*
MEDICINE. Peculiar to, or prevalent in, a particular region or district.

An ENDEMIC *disease is constantly present in a given community, as contrasted with an epidemic disease.*



end moraine \'end mə-'rān\
EARTH SCIENCE. A mass of earth and stone carried by a glacier and finally deposited in the form of a belt or ridge; also called a terminal moraine.

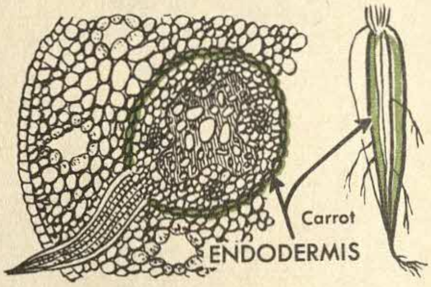
An END MORAINE *marks the furthest position reached by a glacier or ice sheet.*

endocrine gland \'en-də-krən 'gland\
ANATOMY. Any of the ductless glands producing and discharging one or more of the internal secretions called hormones into the blood-vascular system.

The pituitary gland is an ENDOCRINE GLAND.

endocrinology \ˌen-də-kri-'näl-ə-jē\ *n.*
ANATOMY and PHYSIOLOGY. The study of the endocrine glands and their functions.

Investigators working in the field of ENDOCRINOLOGY *have used radioactive iodine to measure thyroid functions.*



endoderm \'en-də-ˌdərm\ *n.*
ZOOLOGY. The inner germ layer of the embryo from which the linings of certain internal organs are formed; also, the inner layer of cells in the bodies of some multicellular lower animals; see also *germ layer.*

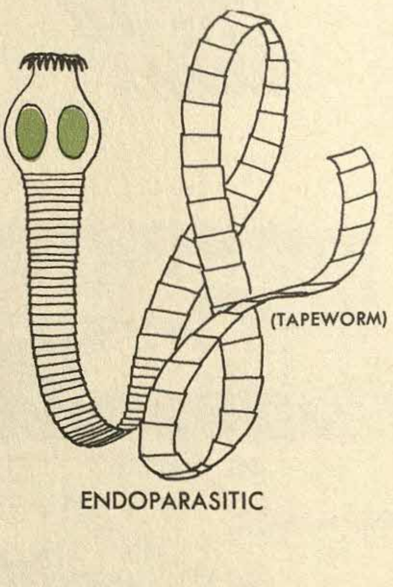
The linings of the respiratory and digestive tracts of the frog develop from the ENDODERM.

endodermis \ˌen-də-'dər-məs\ *n.*
BOTANY. The single layer of living cells located at the inner edge of the cortex of a plant root.

Water entering a plant root must pass through the epidermis, cortex and ENDODERMIS *before moving into the xylem ducts.*

endolymph \'en-də-ˌlim(p)f\ *n.*
ANATOMY. A fluid contained in the membranous labyrinth of the inner ear.

The ENDOLYMPH *is one of the liquids that transmit sound waves in the inner ear.*



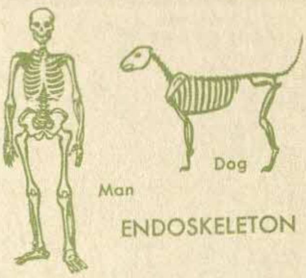
ENDOPARASITIC

endoparasitic \ˌen-(ˌ)dō-ˌpar-ə-'sit-ik\ *adj.*
BIOLOGY. Referring to any parasite that lives in the internal organs of man or animal.

Tapeworms are ENDOPARASITIC *animals that attach themselves to the intestinal walls.*

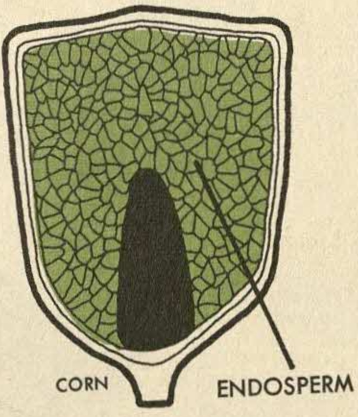
endoplasm \'en-də-ˌplaz-əm\ *n.*
BIOLOGY. The inner, more fluid region of the cytoplasm of a cell.

The nucleus and vacuoles of a cell are located within the ENDOPLASM.



endoskeleton \ˌen-(ˌ)dō-ˈskel-ət-ᵊn\ *n.*
ANATOMY and ZOOLOGY. The bony and cartilaginous framework of the bodies of vertebrate animals.

The ENDOSKELETON *supports the parts of the body and encloses certain soft tissues, such as the brain and lungs.*



endosperm \ˈen-də-ˌspərm\ *n.*
BOTANY. The tissue in some seeds that contains stored food.

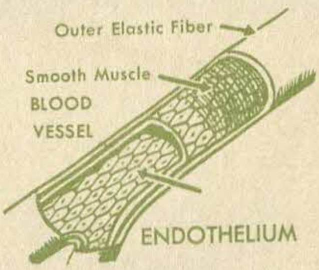
The seeds of corn, wheat and other cereals have an ENDOSPERM.

endothelium \ˌen-də-ˈthē-lē-əm\ *n.*
ANATOMY and ZOOLOGY. A membrane, consisting mostly of tiny, flattened cells, that lines blood vessels and closed cavities of the body.

ENDOTHELIUM *lines the interior of the heart.*

endothermic \ˌen-də-ˈthər-mik\ *adj.*
CHEMISTRY. Referring to a chemical reaction in which heat is absorbed.

When mercuric oxide is heated, an ENDOTHERMIC *reaction results.*

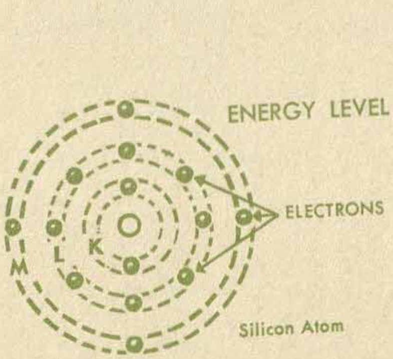


endotoxin \ˌen-dō-ˈtäk-sən\ *n.*
MEDICINE. A toxic substance that is found in certain disease-producing bacteria and that is liberated by the breakdown of the bacterial cell.

An ENDOTOXIN *is always harmful to some tissues of the host animal.*

end point \ˈend ṗoint\
CHEMISTRY. The point in a neutralization reaction at which the quantities of acid and base are chemically equivalent.

The color of an indicator changes at or near the END POINT *of a neutralization reaction.*



energy \ˈen-ər-jē\ *n.*
CHEMISTRY and PHYSICS. The ability to do work; see *kinetic energy* and *potential energy.*

Sound, heat, light and electricity are forms of ENERGY.

energy level \ˈen-ər-jē ˈlev-əl\
CHEMISTRY and PHYSICS. One of the electron shells in which electrons move around an atomic nucleus.

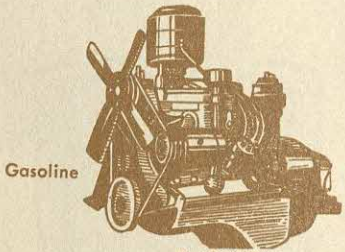
The transition of electrons from one ENERGY LEVEL *to another causes emission of different radiation frequencies.*

engine \ˈen-jən\ *n.*
ENGINEERING. A machine that uses a form of energy, such as heat, to develop mechanical energy.

The ENGINE *of an automobile uses the heat energy of an exploding mixture of gas and air to provide mechanical energy for the drive shaft.*

engineering \ˌen-jə-ˈni(ə)r-iŋ\ *n.*
The art and science of planning and using matter and energy to produce and use such practical products as automobiles, plastics, television and hydroelectric power plants.

ENGINEERING *is essential to a highly-industrialized society.*



ENGINE
(AUTOMOBILE)

enteron \ˈen-tə-ˌrän\ *n.*
ANATOMY and ZOOLOGY. The alimentary canal or digestive tract of an animal.

The ENTERON *is developed during an early embryonic stage.*

enthalpy \ˈen-ˌthal-pē\ *n.*
PHYSICS. The heat content per unit mass of a substance. It is equal to the sum of the internal energy and the product of the pressure and the volume.

When a liquid is boiled, its change in ENTHALPY *is equal to its increase in heat content at constant pressure.*

entomology \ˌent-ə-ˈmäl-ə-jē\ *n.*
ZOOLOGY. The branch of zoology that deals with the study of insects.

Research in ENTOMOLOGY *has resulted in new and improved methods of insect control.*

ENTERON

entropy \ˈen-trə-pē\ *n.*
PHYSICS. A measure of the unavailability of energy in a heat-energy, or thermodynamic, system.

If a physical system is allowed to distribute its energy in the absence of outside factors, the ENTROPY *increases as the available energy decreases.*

enucleate \ē-ˈn(y)ü-klē-ˌāt\ *v.*
1. MEDICINE. To remove whole and clean from an enclosing sac.
2. BIOLOGY. To extract the nucleus from a cell.

A surgeon will always ENUCLEATE *a tumor or cyst if possible.*

environment \in-'vī-rən-mənt\ *n.*
BIOLOGY. The conditions or surroundings outside an individual plant or animal that influence growth and development.

The physical ENVIRONMENT *of an organism may consist of such factors as climate and soil.*

PEPSIN CRYSTALS

ENZYME

enzyme \'en-ˌzīm\ *n.*
CHEMISTRY and PHYSIOLOGY. An organic catalyst contained in a living cell and consisting of protein or protein combined with other substances. An enzyme controls chemical reactions in living matter.

Pepsin is a digestive ENZYME.

eolian \ē-'ō-lē-ən\ *adj.*
EARTH SCIENCE. Referring to deposits formed or produced by the wind.

Sand dunes are EOLIAN *deposits.*

eon \'ē-ən *or* 'ē-ˌän\ *n.*
EARTH SCIENCE. Geologically, one of the longest periods in time consisting of at least two eras; also spelled aeon.

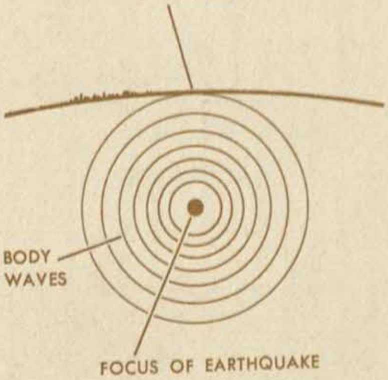
Geologists speak of an EON *as equal to many hundreds of millions of years.*

ephemeral \i-'fem-(ə-)rəl\ *adj.*
1. BOTANY. Referring to a plant whose life cycle is completed within a few days. 2. EARTH SCIENCE. Short-lived, transitory features of the earth's surface, such as intermittent streams.

EPHEMERAL *plants are a prominent feature of the vegetation of the southwestern desert region of the United States.*

ephemeris \i-'fem-ə-rəs\ *n.*
ASTRONOMY. A chart giving the predicted position of a heavenly body at a particular time.

An EPHEMERIS *can be found in an astronomical almanac.*



epicenter \'ep-ə-ˌsent-ēr\ *n.*
EARTH SCIENCE. That region directly over the focus of an earthquake where the movement is most violent.

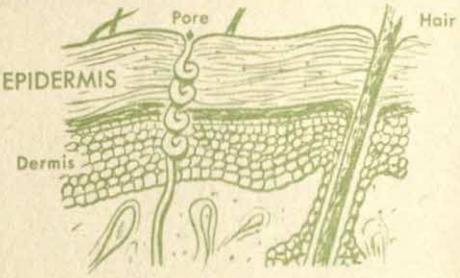
It is possible for scientists to locate the EPICENTER *of an earthquake by using seismographs.*

epicotyl \'ep-ə-ˌkät-ᵊl\ *n.*
BOTANY. The stem region of a plant located between cotyledons and the first true leaves.

The growing tip of a pea plant EPICOTYL *is elevated through the soil by rapid elongation of the epicotyl.*

epicycle \'ep-ə-ˌsī-kəl\ *n.*
ASTRONOMY. In the earth-centered Ptolemaic theory of the solar system, a small planetary orbit having its center on the circumference of a larger planetary orbit, known as the deferent.

The EPICYCLE *was introduced into the Ptolemaic model of the solar system in an attempt to explain the retrograde motions of Mars, Jupiter and Saturn.*



epidemic \ˌep-ə-'dem-ik\ *n.*
MEDICINE. The rapid spread of a highly-contagious disease through a community.

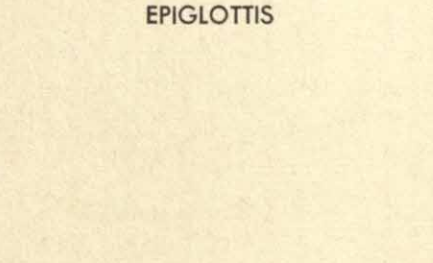
An EPIDEMIC *of influenza can severely disrupt the normal activities of a community.*

epidermis \ˌep-ə-'dər-məs\ *n.*
1. ANATOMY and ZOOLOGY. The outer layer of skin containing no blood vessels and covering the dermis, or true skin, of vertebrate animals. 2. BOTANY. The outermost cell layer of stems, roots and leaves.

The EPIDERMIS *is composed of several layers of dry cells that are renewed, as they are worn away, by cells from deeper layers.*

epigeal \ˌep-ə-'jē-əl\ *adj.*
BOTANY. Referring to the seed leaves appearing above the ground in seed germination.

Green EPIGEAL *growth dotted the garden.*



EPIGLOTTIS

epiglottis \ˌep-ə-'glät-əs\ *n.*
ANATOMY. A thin, lidlike, triangular flap of cartilage that covers the opening of the windpipe during the act of swallowing.

The EPIGLOTTIS *prevents food from entering the windpipe.*

epinephrine \ˌep-ə-'nef-ˌrēn\ *n.*
MEDICINE and PHYSIOLOGY. A hormone produced by the inner core, or medullary portion, of the adrenal glands; also, a hormone prepared synthetically.

When used as a drug, EPINEPHRINE *stimulates the heart muscles to accelerate the heart rate, thus increasing the output of the heart and increasing blood pressure.*

EPIPHYTE

epiphyte \'ep-ə-ˌfīt\ *n.*

BIOLOGY. A nonparasitic plant that does not have roots in the ground and that lives on the surface of other plants.

An orchid may be an EPIPHYTE.

epithelium \ˌep-ə-'thē-lē-əm\ *n.*

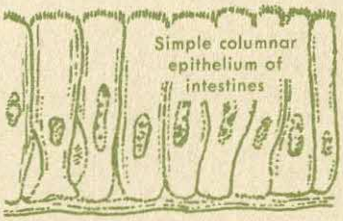
ANATOMY and ZOOLOGY. A cellular tissue that covers internal and some external surfaces of the body, that forms glands and that lines blood vessels and other small cavities.

The EPITHELIUM *is classified according to the shape and structure of its cells.*

epoch \'ep-ək\ *n.*

EARTH SCIENCE. A subdivision of a geologic period.

Mammals became the dominant animals during the Eocene EPOCH.



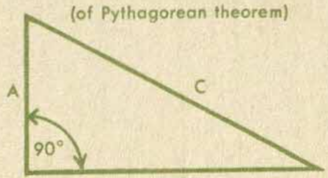
EPITHELIUM

equation \i-'kwā-zhən\ *n.*

1. MATHEMATICS. A statement of the equality of two quantities.
2. CHEMISTRY. A representation of a chemical reaction showing the reactant or reactants and the product or products. If balanced, the equation shows the number of atoms in each element involved and often indicates whether the products are solid or gaseous.

The famous Einstein EQUATION *for the relation of mass and energy is* $E = mc^2$*, in which m is the mass, c is the velocity of light and E is the energy produced.*

$C^2 = A^2 + B^2$
EQUATION
(of Pythagorean theorem)



equation of time \i-'kwā-zhən əv 'tīm\

ASTRONOMY. A formula that equates the difference between mean standard time, as on clocks, and apparent time, as indicated by a sundial.

The EQUATION OF TIME *can be found in an astronomical almanac.*

equator \i-'kwāt-ər\ *n.*

EARTH SCIENCE. An imaginary line that encircles the earth midway between the North and South poles and that divides the earth into equal hemispheres, Northern and Southern. It is located at 0 degrees latitude.

The EQUATOR *is the only line of latitude that is a great circle.*